PUYI SHENG

A Study on Revision Total Knee Arthroplasty

Clinical, Radiological and Survival Patterns

■

ACADEMIC DISSERTATION
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the Faculty of Medicine of the University of Tampere,
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ABSTRACT

This thesis deals with the revision total knee arthroplasty (TKA) operation, which was first evaluated in the light of already published literature, followed by an analysis of the results as reported to the nationwide Finnish Arthroplasty Registry. Subsequently, it was interesting to evaluate the results of such demanding surgery in a specialized unit in which a certain quality strategy was followed, specifically that this kind of surgery was focused to two specialized revision surgeons, who in addition in all cases used a similar modular revision TKA implant system, the Total Condylar III System (TC III). The results were analyzed in the most common indication, osteoarthritis (OA), and compared to what was considered to eventually represent two more demanding situations: inflammatory arthritis and such cases in which major structural bone defects had developed and structural allograft were considered necessary.

The first work of this thesis was a systematic literature review comprising 33 original studies which described patient outcomes following revision TKA. These articles were collected according to a multistage assessment. The meta-analysis results show that the pre-operation values of Knee scores, Function scores and Motion scores were markedly improved ($p < 0.001$). The main indication of revision was loosening, and this was also the main complication after revision surgery. These results suggest that revision TKA was a safe and effective procedure for the patients reported in these studies.

In the second article of this thesis, the nationwide Finnish Arthroplasty Register was used to assess the survival and predictors of survival for revision TKA. 2637 revision TKA from 1990 to 2002 reported to the nationwide Finnish Arthroplasty Register were subjected to survivorship analysis comprising a check-up of the proportional hazards assumption followed by calculations of univariate and multivariate statistics and model diagnostics. The survivorships were 95%, 89% and 79% at two, five and ten years respectively. An age greater than seventy years, revision five years or more after the primary TKA, and absence of patellar subluxation were positive indicators for the survival of a revision TKA. Age was the most significant predictor, though other variables were also of significance, demonstrating, for example, that a history of a long life in service of the primary TKA was a positive predictor. These results suggest that normal aging as well as the conditioning effect of disease and its treatment (primary TKA) perhaps lead to a more sedate way of life, which together with a reluctance to operate on elderly patients protect against the end outcome used in the register, namely re-revision.

Following this, as OA is the most common indication for TKA, the performance of the TC III system was studied with such patients and compared to the outcome in inflammatory arthritis, usually rheumatoid arthritis (RA). 71 cases, 55 OA knees and 16 inflammatory arthritis knees had undergone revision TKA using just this one modular revision prosthesis in our hospital from 1990-2002. The most common reasons recorded as indications for revision were instability and polyethylene wear. Revision operations were performed by two experienced arthroplasty surgeons in all but two cases. At the final follow-up, the total Knee Society Knee score, Function

score and Range of motion had all improved ($p < 0.001$). No differences were observed between OA and inflammatory arthritis in these scores. No knee had definite component loosening with radiolucent lines and symptoms, although 23 knees had asymptomatic radiolucent lines. The complications comprised four infections, one patellar pain syndrome and one rupture of patellar tendon. With prosthesis removal for any reason as the end-point, the 10-year survival rate was 94.7%, whereas with aseptic loosening as the indication for revision as the end-point the 10-year survival was 100%. These results show that focusing demanding revision TKA surgery to a few skilful hands led to good or excellent results and demonstrate that the TC III system has very good potential in such complex knee surgery. In spite of ligamentous laxity, a propensity for infection, more severe bone destruction and poor general health, patients with inflammatory arthritis had results similar to those in OA.

Inflammatory joint diseases impair the quality of soft tissues and bone and the general condition of the patient, and pose a challenge for the surgeon in revision TKA. Furthermore, the previous operation and its failure might have caused extensive bone loss in addition to angular deformity and ligamentous laxity. A consecutive series of revision TKA, using just one modular revision prosthesis (TC III) in patients with inflammatory arthritis, consisted of 16 knees in 14 patients operated on between 1994 and 2000. The patients were followed up for 74 months. The mean preoperative Knee Society Score was 37 points and improved to 88 points at the follow-up ($P < 0.001$), indicating very good overall results. The range of motion improved from 62° to 98° ($P < 0.05$), enabling the patients to stand up from a sitting position. The Knee Society pain score improved from 22 to 44 ($P < 0.05$). No knees had definite component loosening, although 5 knees had asymptomatic radiolucent lines. Complications were seen in 3 cases, and were patellar pain, patellar fracture and infection. These results suggest that the TC III system can be used successfully in revision TKA for inflammatory arthritis.

A major bone defect is also a challenge in revision TKA for the orthopaedist. This was analyzed more closely in a consecutive series of revision TKA performed using a structural bone graft with just one modular revision prosthesis, the TC III system, in 10 knees out of 10 patients operated on between 1994 and 2001. The patients were followed up for 5 years. The mean preoperative Knee Society Score was 39 points and improved to 81 points at the follow-up ($P < 0.05$), indicating very good overall results. The Knee Society pain score improved from 18 to 42 ($P < 0.05$). All structural allografts had a definite union without any signs of resorption. 2 knees had asymptomatic radiolucent lines (< 1 mm). Retropatellar pain was the only complication treated successfully with patellar resurfacing. These results suggest that the TC III system can be used successfully in revision TKA when structural bone grafts are used to fill any eventual major bone defects.

These results suggest that modern TKA revisions are already quite satisfactory operations and the outcome can perhaps be further improved if relatively simple strategies are followed by focusing these operations to specialized revision surgeons who accumulate enough experience from these demanding operations.

LIST OF ORIGINAL PUBLICATIONS

I. Puyi Sheng, Matti Lehto, Matti Kataja, Pekka Halonen, Teemu Moilanen, Jorma Pajamäki: Patient outcome following revision total knee arthroplasty: a meta-analysis. ***International Orthopaedics*** 28:78-81, 2004

II. Puyi Sheng, Liisa Konttinen, Matti Lehto, Daisuke Ogino, Esa Jämsen, Juha Nevalainen, Jorma Pajamäki, Pekka Halonen, Yrjö T. Konttinen: Revision total knee arthroplasty 1990-2002: Review of the Finnish Arthroplasty Register. ***J Bone Joint Surg (Am)*** 88:1425-1430, 2006

III. Puyi Sheng, Esa Jämsen, Matti Lehto, Jorma Pajamäki, Pekka Halonen, Yrjö T. Konttinen: Revision total knee arthroplasty with the Total Condylar III system: a comparative analysis of 71 consecutive cases in patients with osteoarthritis or inflammatory arthritis. ***Acta Orthop Scand*** 77:512-518, 2006

IV. Puyi Sheng, Esa Jämsen, Matti Lehto, Jorma Pajamäki, Pekka Halonen, Yrjö T. Konttinen: Revision total knee arthroplasty with the Total Condylar III system in inflammatory arthritis. ***J Bone Joint Surg (Br)*** 87 :1222-1224, 2005

V. Puyi Sheng, Esa Jämsen, Matti Lehto, Yrjö T. Konttinen, Pekka Halonen, Jorma Pajamäki: Structural Bone Grafts in the Repair of Major Bone Defects in Revision Total Knee Arthroplasty Performed Using the Total Condylar III system. ***Journal of Orthopaedic Surgery***. Submitted.

ABBREVIATIONS

ACL	Anterior Cruciate Ligament
AGC	Anatomic Graduated Components
AP	Antero-Posterior
CAS	Computer-Assisted Surgery
DMARD	Disease Modifying Anti-Rheumatic Drug
HSS	Hospital for Special Surgery
JAMA	The Journal of the American Medical Association
JBJS	The Journal of Bone and Joint Surgery
J&J	Johnson & Johnson
J/W	Joint force/body Weight
KSS	The Knee Society Clinical Rating System
LCL	Lateral Collateral Ligament
MCL	Medial Collateral Ligament
NSAID	Non-Steroidal Anti-Inflammatory Drugs
OA	Osteoarthritis
PCA	Porous Coated Anatomic
PCC	Posterior Cruciate Condylar
PCL	Posterior Cruciate Ligament
PFC	Press Fit Condylar
RA	Rheumatoid Arthritis
ROM	Range of motion
SPSS	Statistical Package for Social Sciences
TKA	Total Knee Arthroplasty
TC III	Total Condylar III system
UK	United Kingdom

1. INTRODUCTION

The first total knee arthroplasty (TKA) was performed in the United Kingdom in 1968. As the number of TKA performed each year continues to increase and the number of patients having a knee replacement continues to grow, the number of patients undergoing revision surgery will also increase as many TKA implants tend to loosen or have to be revised for some other reason such as mechanical breakage or infection (Nevalainen et al. 2003). Revision TKA have traditionally represented approximately 5% of all TKA performed (Bourne and Crawford 1998).

Those patients who undergo revision surgery present a higher degree of technical challenge and the operations themselves are associated with more work and higher risks compared to the primary TKA. Some bone has been lost and it may be weakened due to stress shielding, and the ligaments, joint capsule and muscles providing dynamic support are in general not in as good shape as in patients undergoing primary TKA. The outcome of the revision operation depends on many factors, such as patient characteristics, surgical technique and the implant. Each of these factors is considered to have important implications for the outcome of the operation.

This has raised interest in the factors that affect the outcome of revision TKA. Many studies have been published which indicate somewhat different outcomes for revision TKA (Scuderi and Insall 2000, Hoeffel and Rubash 2000, Rand et al. 1986, Kaufer and Matthews 1986, Mow and Wiedel 1998, Ritter et al. 1991, Haas et al. 1995, Peters et al. 1997b, Christensen et al. 2002). Some of them also describe the operative technique of the revision in some detail (Engh and Ammeen 1998, Engh and Parks 1997, Insall 1982, Scuderi and Insall 2000). This raises many questions about the outcome in general and its predictors. To our knowledge, no study has summarized the literature describing the patient outcome following revision TKA. Furthermore, there are no studies on the results of revision TKA based on a large nationwide data register, which would reflect relatively unbiased patient, surgeon and implant material and some type of national mean. Together, such a systemic literature analysis and register study would provide a relatively reliable picture of the state–of-the-art of revision TKA, as they would to a certain extent support each other. After the mean outcome based on both a literature and register study has been unravelled, it would be interesting to check how such mean results relate to the results attained in a highly specialized total joint replacement unit where these operations are performed in great numbers by a few specialized revision surgeons. Furthermore, even in such a setting the outcome of revision TKA might be different for patients suffering from rheumatoid arthritis (RA) or some other inflammatory arthritis and for those inflicted by the more common degenerative osteoarthritis (OA). Patients with massive bone defects would seem to present a particular challenge. Therefore, a set of studies was performed to assess and compare the outcome of revision TKA in inflammatory arthritis, OA and bone defect patients treated in the Orthopaedic Clinic at the Tampere University Hospital and Coxa, a hospital for joint replacement, which assumed responsibility for joint replacements in the Pirkanmaa Hospital District in

September 2002.

The Total Condylar III (TC III; Depuy, Johnson & Johnson, Leeds, UK) system was designed in 1977 to address the problem of severely deformed knees with ligamentous laxity, which pose an often serious problem for the surgeon in the revision setting (Donaldson III et al. 1988, Kim 1987, Ranawat et al. 1984). Some authors have reported on the use of the TC III prosthesis system in revision TKA (Rosenberg et al. 1991, Rand 1991, Donaldson III et al. 1988, Kim 1987, Ranawat et al. 1984, Bush-Joseph 1989). Its use in the treatment of complex knees in revision surgery has in general provided satisfactory clinical results.

2. LITERATURE REVIEW

2.1 ANATOMY AND BIOMECHANICS OF THE KNEE

2.1.1 NORMAL ANATOMY OF THE KNEE

Joints in general represent junctions between two or more different bones, which can be attached by bone (synostosis), cartilage (synchondrosis), fibrotic tissue (sutures) or by a true joint cavity (synovial joint). The knee (Figure 1) is the largest synovial joint of the human body and it is also one of the most complex. It is formed of three compartments. The knee area contains four different bones, which are connected by supporting and guiding muscles, the joint capsule, ligaments, menisci, tendons, bursae and infrapatellar fat body. Such strong components are necessary as the knee carries very high and dynamic loads and is therefore subjected to considerable biomechanical stresses and strains. (Williams et al. 1989)

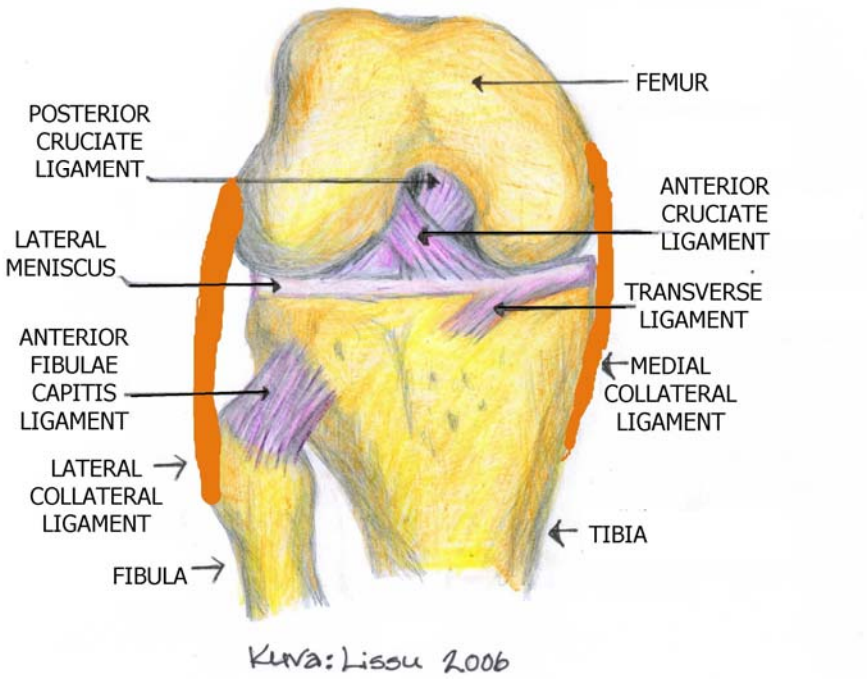

Figure 1. Anatomy of the knee. The patella, with the associated quadriceps tendon and patellar ligament, has been removed to expose the interior structures of the knee joint.

The femur is the large bone of the thigh, whereas the tibia is the large shin bone. The femur is the longest bone of the human body, which in its lower end divides into two strong condyles, the medial (tibial) condyle and the somewhat smaller lateral (fibular) condyle. Both are flanked by epicondyles for muscle attachment. These two convex condyles are at their inferior and posterior aspects separated by an intercondylar groove. The posterior, inferior and anterior surfaces of the femoral condyles are covered by hyaline articular cartilage.

The tibia is the long and tri-facetted long bone of the shin, which in its thickened proximal end contains a plateau composed of the upper surfaces of two condyles (medial or tibial and lateral or fibular) separated by an intercondylar eminence. The tibial condyles correspond their shape to those at the distal end of the femur and contain shallow, rounded and concave articular facets covered by hyaline articular cartilage flanked in their peripheral proportions by fibrocartilaginous menisci (medial and lateral), which act as adapters. Thus, the two condyles of the femur and the two condyles of the tibia form two important compartments or counterfaces of the knee joint, the medial and lateral tibiofemoral joints.

The third compartment of the knee joint is the patellofemoral joint. The patella, also known as the knee cap, is a sesamoid bone in the front of the knee (femur). It is embedded between the quadriceps tendon and the patellar ligament, which is fixed to a bony tuberosity, the tuberositas tibiae. The proximal part (basis) of the patella is relatively wide and its sides converge to a blunt head in its distal end so that its overall form is somewhat triangular. The patella is on its underside covered by hyaline articular cartilage and it slides up and down in a cartilage-covered groove in the femur, the femoral groove, as the knee bends and straightens.

The fibula is the smaller shin bone, located just lateral to the tibia flanking it and articulating in its upper end to the posterior aspect of the lateral condyle of the tibia. The fibular is part of the “knee”, but the tibio-fibular joint is not considered to be part of the actual knee joint. (Williams et al. 1989)

The important internal parts of the knee include articular cartilage, subchondral bone plates, meniscal cartilage, ligaments, and tendons. As already referred to above, there are two types of cartilage in the knee. The articular cartilage proper, the hyaline articula cartilage, contains specialized collagen type II- and XI-rich and collagen type IX decorated fibres, which form the backbone of the tissue that covers the ends of the bones (Kumbar et al. 2005). Elasticity is provided by the hydrophilic proteoglycan known as aggrecan and bound to the hyaluronan core. The cellularity of hyaline articular cartilage is relatively low. Meniscal cartilage is specialized fibrocartilaginous tissue located around the perimeter of the knee. Articular and meniscal cartilage help to distribute the load and menisci provide some stability to the knee. Further stability is provided by ligaments attached to the femur and tibia and also by several tendons, strong bands of fibrous tissue, which connect muscle to bone at the enthesis. The weight of the body is transferred through the femur, across the knee joint and into the tibia. The large muscles in the front of the thigh (the quadriceps) straighten the knee (extension), whereas the large muscles at the back of the thigh (the hamstrings) bend it (flexion). The patella functions as an important lever for the quadriceps muscles, making the muscle more efficient.

In addition to the “anterior” ligament (ligamentum patellae) and quadriceps tendon, four other main ligaments support the knee. On the inner (medial) aspect of the knee is the broad medial collateral ligament, and on the outer (lateral) aspect of the knee the cord-like lateral collateral ligament. Together, with the dynamic protection provided by muscles and tendons, they strengthen the knee capsule to help stabilize

the knee joint particularly sideways (side-to-side stability), i.e. against excessive valgus (medial ligament) and varus (lateral ligament) deformations. The other two main ligaments, cruciate ligaments, cross each other in the centre of the knee. The anterior cruciate ligament is fixed to a depression in front of the intercondylar eminence on the tibia and to the medial aspect of the lateral condyle of the femur. The posterior cruciate ligament is fixed to a depression behind the intercondylar eminence on the tibia and on the lateral aspect of the medial condyle of the femur. These ligaments are like strong ropes that connect the bones and provide stability to the knee joint, in particular by controlling forward and backward sliding of the tibia in relation to the femur.

Antero-posterior (frontal) and lateral (side) x-ray views of a normal knee are shown in Figure 2. The thigh bone (femur) is on the top and the leg bone (tibia) on the bottom. The smaller bone in the leg is the fibula. The knee cap (patella) can be seen in front of the knee in the side view. The apparent space between the bones is actually occupied by articular cartilage, but as it does not contain radiodense calcium, it is seen in the radiographs as an empty space called the joint space. (Williams et al. 1989)

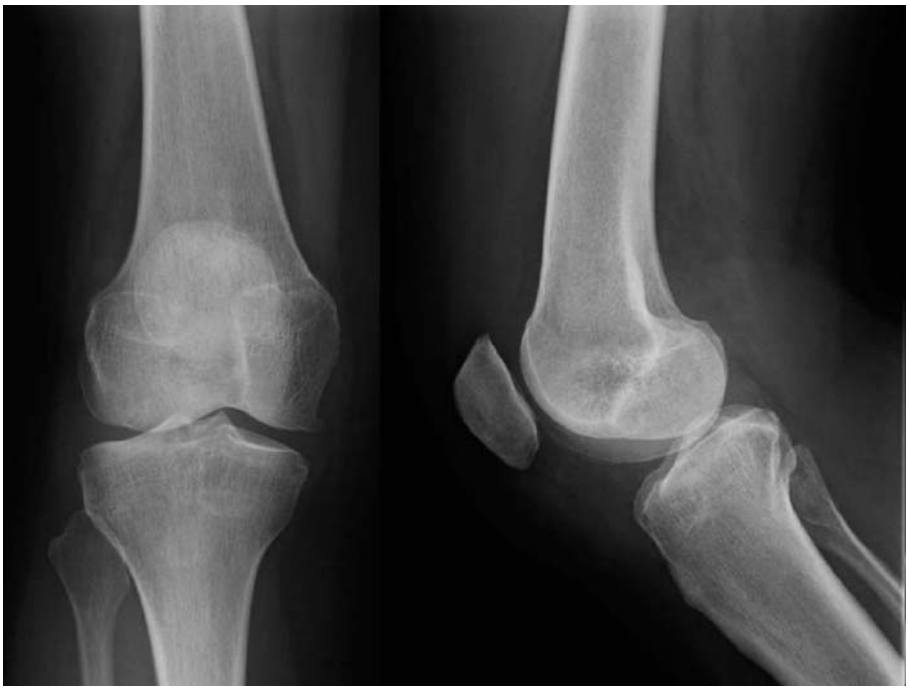

Figure 2. Antero-posterior (frontal) and lateral (side) x-ray views of a healthy knee joint.

2.1.2 BIOMECHANICS

2.1.2.1 Movement

Kinematics is the branch of mechanics which describes the joint motion without reference to the forces producing them. Thus, it defines the motion of the knee joint in

the frontal, sagittal and horizontal planes. The knee is conventionally considered to be a hinge joint, though some “screw-home” rotation also occurs to adapt the complex surface of the knee joint during flexion-extension (see below for details). Movement of the knee joint has in principle 6 degrees of freedom: 3 translations (including anterior/posterior, medial/lateral, and inferior/superior) and 3 rotations (including flexion/extension, internal/external, and abduction/adduction. The primary motion, however, occurs in the sagittal plane and according to goniometry ranges from 0 to 140 degrees. In addition to or combined with this, enabling locking and unlocking, a slight external or internal rotation is also possible as is explained below. During the gait cycle the knee flexion reaches its maximum flexion, approximately 65 degrees, during the toe-off phase. In the patellofemoral joint, movements occur in two planes, with the greatest motion occurring in the frontal plane. As a result, the patella causes anterior displacement of the quadriceps tendon. This increases the lever arm of the extensor apparatus and aids knee extension. This also helps distribute the compressive forces in the patellofemoral joint to a relatively wide area. (Helfet 1974, Insall and Scott 2001)

Movements of the knee joint are co-operatively guided by the shapes of the joint surfaces of the tibia and femur and by the orientation of the major ligaments of the knee joint, including the anterior and posterior cruciate ligaments and the medial and lateral collateral ligaments. The stabilizing 4-bar ligament complex plays an important role in the dynamic stability of the knee during knee movements. This is particularly important because this joint is located between the two longest lever arms of the body, which naturally produces considerable forces during cyclic loading. (Helfet 1974, Insall and Scott 2001)

The cruciate ligaments enable the knee to both roll and slide, but at the same time they also maintain joint surface contact and provide stability, in particular in the antero-posterior orientation. Knee extension can be envisioned as a movement during which the tibia glides forward on the femur. During the last phase of this movement, starting approximately 20 degrees before full extension, the tibia in addition rotates externally (with respect to the femur), leading to external tibial rotation. During this last important phase of extension, it is only the medial condyle of the tibia which continues to glide. This is possible as it is larger in size than the lateral condyle. The smaller lateral condyle cannot continue to glide further as it has already reached its farthermost position due to its shorter length. This continuing anterior glide in the medical compartment automatically produces external tibial rotation, something which is known as a “screw-home” type locking mechanism. This knee-locking mechanism stabilizes the knee in its fully extended position so that we can stand up with relatively little use of active muscle energy (Helfet 1974, Insall and Scott 2001).

The flexion and extension of the knee represents a combination of rolling and sliding movements which is known as femoral rollback. This allows increased ranges of flexion. In this instance, it is useful to consider the degree of flexion required for important activities in daily living. 65 degrees of flexion is required to walk at a normal pace (this flexion angle increases as the speed increases from slow walking to

fast running), 90 degrees of flexion to walk up or down stairs; 95 degrees is required to rise from or sit down in a chair, 105 degrees to put on shoes and 120 degrees to lift an object from the floor without the use of an aid. These are useful approximate figures when the range of motion (ROM) and functional abilities before and after joint arthroplasty operations are evaluated (Helfet 1974, Insall and Scott 2001).

The movement of the patellofemoral joint can be characterized as gliding and sliding. During flexion of the knee, the patella moves distally along the femur. This is achieved with the help of attachments of the patella to the quadriceps tendon and patellar ligament and the guidance provided by the anterior aspects of the femoral condyles. The extensor muscles and ligaments of the patellofemoral joint produce knee extension. The patella can be seen as a pulley which transmits the force developed by the quadriceps muscles to the femur and the patellar ligament. The patella mechanically enhances the power effect of the quadriceps muscle relative to its instant centre of rotation of the knee (Helfet 1974, Insall and Scott 2001).

2.1.2.2 Carrying load

Body weight passes along the mechanical axis (an imaginary line) of the lower limb. This line starts from the centre of the hip and continues to the centre of the ankle, passing through the middle part of the knee joint. This ideal mechanical axis is altered in deformed knees which display valgus or varus deformities. Malalignment increases and impairs the transmission of forces to which the knee joint is subjected. This naturally aggravates degeneration of the knee (secondary osteoarthritis) and can contribute to knee pain due to knee strain. Knee surgery aims to restore the normal alignment and mechanical axis to normalize the gait and to protect the knee prosthesis from eccentric loading and early failure. During walking, the knee joint is subjected to forces which exceed the body weight 2- to 4-fold. A major portion of this load, approximately 50-100%, is transmitted through the meniscus. The menisci can be regarded as joint adapters which increase the contact surface area between the rounded femoral condyles and its tibial plateau counterface on the medial side, and the convex tibial plateau counterface on the lateral side. This improved adaptation plays an important role in proper load transmission in healthy joints. After meniscectomy, the forces concentrate on a much smaller area, which leads to high peak loads and enhanced wear. In a healthy knee, approximately two-thirds of the total load passes through the larger medial and one third through the smaller lateral compartment. (Insall and Scott 2001)

2.1.2.3 Stability

As already mentioned above, the cruciate ligaments enable simultaneous rolling and sliding of the knee while at the same time maintaining good contact and knee stability. Cruciate ligaments stabilize the knee in particular in the forward and backward orientation, whereas the two other ligaments of the 4-bar system (collateral ligaments)

strengthen the knee by providing considerable side-to-side stability. The primary function of the medical collateral ligament is to restrain valgus rotation of the knee joint, accompanied with a secondary function to control external rotation. The lateral collateral ligament restrains primarily varus rotation, but also protects against excessive internal rotation. The main functions of the anterior cruciate ligament are to prevent anterior displacement of the tibia on the femur when the knee is flexed (tested using the drawer test) and to guide the screw-home locking mechanism achieved with the external rotation of the tibia in its terminal extension. Another function of this ligament is to resist varus or valgus rotation of the tibia, in particular in such knee positions which lead to relaxation of the collateral ligaments. A third function of the anterior cruciate ligament is to resist internal rotation of the tibia. The main function of the posterior cruciate ligament is to allow femoral rollback in flexion and to prevent posterior gliding of the tibia relative to the femur (tested using the drawer test). The posterior longitudinal ligament also externally rotates the tibia in increasing knee flexion. For these reasons, retention of the posterior longitudinal ligament in total knee replacement also retains the knee biomechanics that provide normal kinematic rollback of the femur on the tibia, and helps maintain the lever arm of the quadriceps in knee flexion. (Insall and Scott 2001)

As mentioned above, a locked and fully extended knee is quite stable so that minimal effort of the knee extensor apparatus is needed to keep the body's centre of gravity almost directly above the knee as the knee ligaments take the load.

2.1.2.4 Gait

As a lower-extremity joint enabling our movement, the knee is essential for everyday activities such as walking, climbing stairs, and rising from a chair. Each of these activities has its unique biomechanical characteristics and load patterns, but the most important activity is simple level walking. Walking can be envisioned as a repeated multitude number of basic gait cycles, which can in its kinematic and kinetic analysis be separated into different components and phases.

The product of the number of daily walking cycles and 365 has been used to estimate that an average adult takes some 0.9-1.5 million steps per year (Wallbridge and Dowson 1982, Seedhom 1985). The maximum load the knee reaches during walking is approximately 3 times the body weight (Figure 3). During each gait cycle, certain repeated movements lead to corresponding cyclic eccentric loading of the tibial component as it causes cyclic rocking stress on the joint surface and at the bone-cement-prosthesis interface. The cyclic loading and the associated micromovement are probably important for the aseptic implant loosening, especially for their early migration (Tibone et al. 1986; Hilding et al. 1996). Other more rare but still common activities, such as climbing stairs or rising from a chair, lead to higher torsional loading than simple level walking (Hodge et al. 1989).

The normal knee flexes twice during the gait cycle, first during the loading response phase to approximately 15 degrees, and a second time beginning at preswing,

reaching a midswing peak of 60-65 degrees. The maximum stance-phase flexion angle in jogging reaches 44.3 ± 5.2, when ascending stairs 66.7± 5.8, and when descending stairs ± 63.9 degrees. A maximum 5-degree extension is reached in midstance. The mean range of motion during level walking has been estimated to be 61 degrees. Knee flexion during the limb-loading phase of gait is approximately 15 degrees, and the average range of knee motion 96 degrees during stair descent and stair ascent (Insall and Scott 2001).

Total knee arthroplasty improves the biomechanics of walking, and marked improvements also occur in other functions, though gait abnormalities often still remain (Andriacchi et al. 1982, Andriacchi et al. 1986, Weinstein et al. 1986, Kelman et al. 1989, Steiner et al. 1989, Mattsson et al. 1990, Schnitzer et al. 1993). Gait studies have helped improve prosthetic design to reach balanced load-sharing between the prosthesis and ligaments. In addition, our understanding of the mechanical causes of prosthesis loosening has deepened. The current knee prosthesis designs (sparing or substituting of the posterior cruciate ligament) and rehabilitation techniques (preventing quadriceps weakness) contribute to a good or excellent clinical outcome. Although the procedure often restores excellent overall functional performance, some abnormalities in locomotion function remain after total knee arthroplasty (Morrison 1970, Rittman et al. 1981, Andriacchi et al. 1982, Olsson 1986, Dorr et al. 1988, Schipplein and Andriacchi 1991)

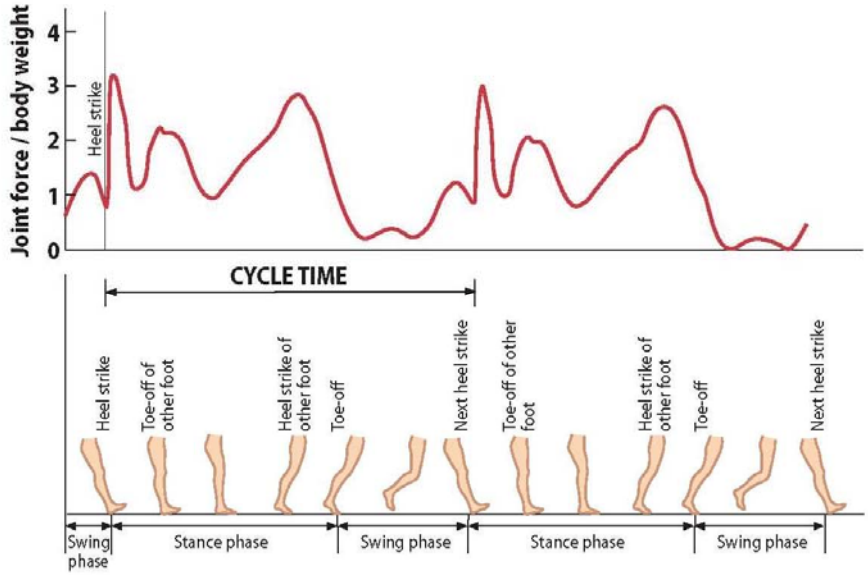

Figure 3. The Paul gait curve for a knee during regular walking. The J/W refers to the joint force to body weight ratio. The maximum and minimum estimates of the loads in the vertical y-axis are given using a continuous line. It can be seen that the maximum load the knee is subjected to during walking reaches approximately 3 times the body weight (see the scale to the left). The gait cycle starts when the heel of the forward foot first touches the ground. This leads very rapidly to a load peak in the knee, followed by a small valley, a second smaller peak, a valley and a third peak reached before the heel of the other foot touches the ground.

2.2 ARTHRITIS

2.2.1 Osteoarthritis

Osteoarthritis is the most common form of arthritis, also known as a degenerative joint disease as it becomes more frequent with aging. It causes pain, swelling and reduced motion in joints. It can occur in any joint, but usually it affects the knees, hips or spine. Most cases of OA are primary because they have no known cause and no predisposing factor is apparent. When the cause of the OA is known, for example a trauma, the condition is referred to as secondary OA. Factors causing a predisposition to OA include excessive weight, aging and joint injury (Braunwald et al. 2001a).

Osteoarthritis breaks down the cartilage in joints. Cartilage is the slippery and elastic tissue that covers the ends of bones in a joint. Healthy cartilage absorbs the shock of movement. When cartilage is lost, bones start to rub against each other. In the knee, OA affects the medial or lateral femorotibial compartments and/or the patellofemoral compartment. OA in the medial compartment of the knee may result in a varus deformity, whereas OA in the lateral compartment may produce a valgus deformity (Braunwald et al. 2001a).

The aims of therapy for OA are to reduce pain, improve function and minimize disability. Therapy includes exercise, weight control, rest, pain relief, alternative therapies and surgery. Knee surgery is usually reserved for those patients with OA who have particularly severe disease and are unresponsive to conservative treatments. Arthroscopy can be helpful when cartilage tears are suspected. Osteotomy may in selected patients help realign some knee deformities and relieve pain. In some cases, severely degenerated joints are best treated by replacement with an artificial joint. Total knee replacements are now commonly performed worldwide in orthopaedic hospitals. This operation can bring dramatic pain relief and improved function. Excellent outcomes from primary TKA in OA patients have been reported by many experts (Gioe et al. 2007, Mont et al. 2002, Thadani et al. 2000)

2.2.2 Inflammatory Arthritis

Inflammatory arthritis is a condition in which the synovial membrane is inflamed, i.e. characterized by synovitis. It is one of the most common causes of chronic disability, but its etiology remains elusive. Many forms of inflammatory arthritides are autoimmune disorders in which the body's immune defence reacts against its own tissues. They include RA, lupus, ankylosing spondylitis, Reiter's syndrome, psoriatic arthritis, juvenile chronic arthritis, etc. Arthritis is often an inherently progressive illness that has the potential to cause joint pain, destruction and functional disability (Braunwald et al. 2001b). Seronegative arthritides are often also characterized by two more histopathological features: new bone formation leading to whiskering, periostitis,

fish tail formities, enthesophytes, paravertebral calcifications etc., and enthesopathies, which refers to inflammation and bone formation at the site where tendon, capsule and ligament enter the bone, e.g. Achilles tenditis and plantar fascitis.

The characteristic symptoms of an inflammatory arthritis reflect its inflammatory nature and comprise *rubor*, *tumour*, *dolor*, *calor* and *functio laesa*. Arthritis is characterized by pain and swelling of one (monoarthritis), a few (oligoarthritis) or many joints (polyarthritis), which may also be warmer than the other joints. Stiffness in the joints on getting up in the morning, or after sitting still for a while, is very common and sometimes the very first symptom. These symptoms lead to impaired functions, in the case of the knee, for example, to difficulties in walking and stair climbing. When treating these diseases, modern medical practitioners focus on relieving the symptoms, slowing the progression of the diseases and preventing progressive damage to articular structures. Conventional medical treatments may help to relieve the symptoms of inflammatory arthritis, but they do not address the root of the problem. The main treatment is the use of non-steroidal (Non-Steroidal Anti-Inflammatory Drugs, NSAID) and steroidal (e.g. prednisone) anti-inflammatory drugs and, in particular, disease modifying anti-rheumatic drugs (DMARD). For example, in Finland often a combination of low dose prednisone, sulphasalazopyrin, methotrexate and oxichloroquine is used. New treatment strategies include early treatment, combination treatment, saw tooth strategy and the use of new "biologicals" like tumour necrosis factor blockers (Konttinen et al. 2005). This approach can simply slow the progression of the disease but not really cure it. In long-term use, DMARDs and in particular prednisone and NSAIDs can cause a host of problems including hematological complication, liver damage, osteoporosis, gastric perforations, ulcerations and bleeding, immune suppression and infections, weight gain, bloating, thin skin and many other troubling side effects (Braunwald et al. 2001b).

When patients suffer joint destruction and functional disability, surgical approaches are necessary to improve the quality of life. Current, excellent outcomes from total joint arthroplasties, particularly of the knee, hip, wrist, and elbow, are obtained in patients with inflammatory arthritis, and they can be highly successful in reducing pain and improving joint function (Braunwald et al. 2001b, Laskin and Ohnsorge 2005). However, because of the progressive nature of this disease and the side effects of conventional medical treatment, the TKA and the revision program will be a complex and difficult process for the surgeon.

2.3 INDICATIONS FOR REVISION TOTAL KNEE ARTHROPLASTY

According to literature dealing with revision TKA, aseptic loosening of the implants is the most common indication for revision TKA. Friedman et al. analyzed 137 revision TKAs performed on 117 patients with failed aseptic metal-to-ultra high molecular weight polyethylene knees over ten years. The most common reasons for failure were aseptic loosening (73%), patellar complications (13%), and instability (10%) (Friedman et al. 1990). Reports on consecutive series of revision TKA show that aseptic loosening is the main indication for revision (Barrack et al. 2000b, Mow

and Wiedel 1994, Bryan and Rand 1982). Recently, based on The Swedish Knee Arthroplasty Register, aseptic loosening was found to be the cause of revision in 44-50% of patients with a failed primary TKA (Robertsson et al. 2001, Sundfeldt et al. 2006).

Polyethylene wear and a foreign body reaction with an associated osteolysis around TKA implants have been regarded as significant problems after TKA (Gupta et al. 2007, Naudie et al. 2007, Riaz and Umar 2006). In the early stages after arthroplasty, Hood et al. found that the surface damage to polyethylene was in a significant positive correlation with the patient's weight and the time the prosthesis had been implanted (Hood et al. 1983). Following this report, many other publications have supported this view. For instance, Wright et al. analyzed many retrieved porous coated anatomic (PCA) tibial components and always found significant polyethylene wear (Wright et al. 1992). In a study by Benjamin et al, the most common reason for revision surgery was loosening (40%), followed by polyethylene wear (21%), and osteolysis (21%) (Benjamin et al. 2001). Many other studies also show that, apart from loosening, polyethylene wear and osteolysis are often the main causes of revision surgery to knee arthroplasties (Barrack et al. 2000a, Hanssen 2001, Friedman et al. 1990).

Despite the indications mentioned above for revision TKA, problems with the extensor mechanism and patellofemoral joint pain developing after TKA continue to be the most common cause of pain problems in the operated knee. This forms a commonly cited reason for revision surgery. This complication comprises patellar instability, component loosening, patellar fracture, patellofemoral pain of unknown origin, patellar dislocation, patellar subluxation, patellar tendon avulsion, and clunk. Thornhill et al. reported that complications related to patellofemoral articulation were the cause of TKA revision in up to 45% of all cases (Thornhill et al. 1982). The prevalence of patellar complications in TKA has been reported to range from 5% to 25% (Burnett et al. 2004, Waters and Bentley 2003). The ability to diagnose complications in the patellofemoral joint and to treat them appropriately is a necessity for the surgeon who performs revision TKA (Rosenberg et al. 2003).

Other often cited indications for revision operations are instability, infection, bone fracture, component failure, disease progression, joint stiffness or unspecified reasons (Bradley 2000, Barrack et al. 2000b, Barrack et al. 2000c, Barrack et al. 2004, Benjamin et al. 2001, Friedman and Poss 1988, Friedman et al. 1990, Fehring et al. 2002, Harwin 2006, Hernigou et al. 2005, Hofmann et al. 2005, Jacobs et al. 1988, Luria et al. 2003, Rand and Bryan 1988, Rand 1991, Murray et al. 1994, Mow and Wiedel 1994, Mow and Wiedel 1998, Kaufer and Matthews 1986).

2.4 CHOICE OF IMPLANT FOR REVISION TOTAL KNEE ARTHROPLASTY

2.4.1 Implant types

Revision TKA implants have evolved from fully-constrained (linked, fixed-hinge) to semi-constrained and finally to contemporary designs. In fully-constrained, hinged implants, the femoral and tibial components are physically linked to each other, like in a hinge. The advantage of this design is a stable implant, which due to its inherent stability does not require much ligamentous and bony support. It is therefore mainly used in revision and tumour surgery when such supporting host structures have been badly compromised by disease and/or for iatrogenic reasons. The drawback of these fully-constrained, hinged implants is also due to their inherent stability, as constraint supraphysiological force peaks are produced by regular motion. The opposite of such fully-constrained, linked hinge prosthesis are unconstrained implants, which are not mechanically limited in their movements, but instead rely on the conforming joint surfaces and soft tissue guidance. They are characterized by very low constraint forces over the entire physiological range of motion. Semi-constrained implants have near physiologic constraint and are divided into posterior cruciate ligament-preserving, posterior cruciate ligament sacrificing or posterior cruciate ligament-substituting types. The contemporary constrained designs include non-linked constrained (Total Condylar III system, Depuy, Johnson & Johnson, Leeds, UK) designs and rotating-hinge designs. For limb-salvage procedures after tumour resection and massive segmental bone loss, modular segmental replacement designs and allograft-prosthesis composites are used. Modular segmental replacement designs are rotating-hinge components with modular stems of varying length that are used to replace segmental femoral or tibial diaphyseal bone loss (Nelson et al. 2003).

The TC III design is the most constrained device available within the P.F.C.® Sigma™ Knee System. Its use is indicated in cases where collateral ligaments are deficient. This system has a femoral box and a tibial spine that matches the box on the femoral component, which provides stability and constraint; in the tibial component, a titanium reinforcing pin within the spine both reinforces under high loads and transmits high loads from the box onto the tibial tray, and also its rounded coronal and sagittal geometries match the geometry of the femoral component to provide maximum conformity and stability; at the same time, the stem provides advantages for intra-operative flexibility to adapt the placement of the femoral and tibal component to the patient’s anatomy. Therefore, this system’s approach to revision knee surgery provides the surgeon with maximum intraoperative flexibility and good options for complex situation during the revision TKA (© DePuy 2005-2006).

2.4.2 Principle of implant selection

The goals of revision TKA are to obtain stable fixation of the prosthesis to the host

bone, to restore the height of the joint line, to obtain a stable range of motion compatible with the patient's activities in everyday life, and to achieve these goals while using the least degree of prosthetic constraint so that soft tissues share part of the transferred loads. As prosthetic constraint increases, the soft tissues participate less in load-sharing and stresses on the implant-bone interface increase, with the attendant risk of early loosening of the implant.

Implant selection is based not only on the bone status but also on the state of the stabilizing soft-tissue structures, for example the status of the ligaments at the time of revision surgery. In case of ligamentous loss or laxity, a shift from a posteriorly stabilized prosthesis to a non-linked constrained or rotating-hinge prosthesis may be necessary. If there is massive segmental bone loss, a modular segmental replacement prosthesis or an allograft-prosthesis composite may be required (Nelson et al. 2003).

To analyze the effect of the selection of the prosthesis for the outcome of revision TKA, Bugbee produced a retrospective review of 139 consecutive revision TKAs using (a) primary implants, (b) modified primary implants, and (c) revision implant systems. With a mean follow-up of 7 years, they reported 26% failure rates in group a, 11% in group b, and 3% in group c. Although there was a bias towards the use of revision implant systems in the more difficult revision situations, group c with revision implant systems provided superior performance and durability when compared with the other two groups. It was concluded that the use of revision implant systems is justified due to their improved longevity and function (Bugbee 2001, Goldberg et al. 1988). Also, another early study suggested that the use of primary TKA components cannot be recommended in revision TKA (Goldberg et al. 1988).

2.5 CHALLENGES IN REVISION TOTAL KNEE ARTHROPLASTY

2.5.1 Situation before the revision replacement of the knee joint

Revision TKA is much more complex and technically more difficult than first-time TKA, and requires a prolonged operating time. In the revision process, the surgeon is faced with problems not frequently seen in primary TKA. These include bulk bone defect, serious malalignment, component breakage, periprosthesis fracture, infection, stiffness, osteolysis, prosthetic loosening and the progression of arthritis (Vince and Long 1995). According to the principles of revision TKA, similar to those followed in primary TKA, the surgeon should try to restore the original anatomy of the knee, regain function, and provide stability. To achieve these objectives, bone reconstruction, balancing of the soft tissues and restoration of the alignment are more important than in the primary TKA and highly relevant to a good outcome from the revision TKA operation (Riaz and Umar 2006).

2.5.2 Bone

Bone defects are commonly encountered in revision TKA. Osteolysis driven by polyethylene wear debris and other wear particles ("particle disease") often contributes to this end. As many patients undergoing revision TKA are old and suffer from basic diseases like RA and/or osteoporosis, their bone stock is already primarily compromised so that the quantitatively small and qualitatively weak bone easily breaks down, especially when the cemented or cementless prosthetic implant has to be removed during the revision operation when the implant bed for the revision implant is prepared. Patient-related reasons accepted, poor surgical technique and the material and design of the implant can also contribute to the failure of both the primary and revision TKA operations.

Currently, three options can be used to enable the reconstruction of bone defects; 1) augments, 2) cement and 3) bone grafts. Satisfactory results have already been reported in literature on the use of augments, cement and autologous bone grafts for smaller bone defects in revision TKA. Major defects may not be as easy to treat with augments or cement wedges that form an integral and vital part of modern knee revision surgery. The use of structural allografts could provide a useful option for the treatment of massive bone defects, and some preliminary results already suggest as much.

2.5.3 Soft tissue

Common clinical deformities in failed primary TKAs include varus deformity, valgus deformity, flexion contracture and defective patellar tracking. These deformities are probably caused by an imbalance of the soft tissues around the knee joint. A relative contracture exists at the concave side of the deformed knee, while a comparative "excess" in the soft tissue envelope exists on the opposite, convex side. Scar tissue, which develops as a result of TKA, is one of the reasons for such a development.

One common reason for revision TKA is an improper soft tissue balance. Good soft tissue balance may be as important as perfect bone cuts. Inadequate soft tissue balance eventually leads to instability, pain and loosening. Perfect soft tissue balancing requires a good operative technique. The orthopaedic surgeon must try to establish correct alignment of the tibia with respect to the femur and ankle, and attain a balance of the tensions in the surrounding capsular ligamentous sleeve.

Medial and lateral soft-tissue releases are used to correct varus and valgus deformities in primary TKA. They are achieved with a sequential release of tight soft-tissue contractures, occasionally combined with a shortening of the elongated ligaments. In primary TKA, soft-tissue constraints are typically caused by well-defined anatomical structures, whereas in revision TKA the soft-tissue constraints and laxities may be ill defined and haphazard thickened and scarred tissues associated with attenuation or lack of supporting and guiding normal or "anatomical" connective tissues and

structures. Soft-tissue balance in revision TKA can often only be achieved by a combination of soft-tissue releases and bone resections, together with proper implant positioning and the use of implants of an optimal size (Ries et al. 2004, Ries et al. 2003).

2.5.4 Alignment

The mechanisms responsible for the failure of primary TKA are fairly well established. Restoration of the neutral alignment of the leg is an important factor which affects the long-term results of TKA (Bäthis et al. 2004). If the malalignment is very severe, revision surgery soon becomes necessary (Amira et al. 1995). In a study by Ritter et al. (Ritter et al. 1994), 421 TKAs using Posterior Cruciate Condylar (PCC) were analyzed with regard to the femorotibial angle, which normally lies within 5° and 8°. In that study, the highest rates of aseptic loosening were found in patients with a varus malalignment. Jeffrey et al. analyzed the outcome after Denham knee replacement in 115 patients using the earliest design of components, inserted with intramedullary guide rods. They found prosthetic loosening in 24% of cases if the mechanical axis exceeded ±3° varus/valgus deviation, while the corresponding figure was only 3% for those patients with an axis within this ±3° range (Jeffrey et al. 1991).

Overall, malalignment is more commonly a threat in revision than primary TKA as the revision operation is technically more demanding. However, the principles for both the primary and revision TKA are the same. Restoration of the correct alignment should be a high priority for the orthopaedic surgeon and the operation team.

2.6 Principle of revision total knee arthroplasty

Revision TKA is not a repeat primary arthroplasty, but it is a technically demanding procedure. Conceptually, the objectives of the revision arthroplasty operation are the same as those of the primary surgery, i.e. to restore the original anatomy of the knee, to regain function and to provide stability. Despite the fact that revision TKA necessitates some surgical compromises, the principles of primary and revision TKA surgery are also the same (Scuderi 2001). For a successful revision arthroplasty, one should clarify the cause of failure, use adequate surgical exposure, restore limb alignment, achieve soft tissue balance, use correct implant alignment, restore the joint line and obtain a good range of motion (Riaz and Umar 2006). In recent years, many experts have nicely summarized these goals and suggested that enough attention should be paid to the failure mechanisms, to careful planning of the operation, to adequate surgical exposure, to extraction of the failed implants, to the avoidance of any unnecessary bone resection, to filling the eventual bone defects, to restoration of the joint line, to selection of an appropriate revision implant, to joint stability, to optimal rehabilitation, and to avoidance of complications (Bourne and Crawford 1998, Callaghan et al. 2005, Gustke 2005, Mahoney and Kinsey 2006, Mihalko and Krackow 2006).

2.7 Examination

2.7.1 Clinical examination

An adequate patient history is essential before the patient is examined. This provides a clue to the diagnosis, failure mechanisms, and severity of the condition and its impact on the functionality and quality of life of the patient. It will also ensure that the physical, radiological and other subsequent examinations can be properly directed.

The patient history should include questions about any general symptoms, pain, tenderness, joint swelling, joint deformity, limitations of ranges of movement and whether these restrict activities in daily living and leisure time. The patient should be asked about any treatments hitherto applied to his or her current complaints, their effectiveness and eventual adverse effects at the same time as patient compliance should be assessed. General and specific questions should be posed about comorbidity, including past medical and surgical history and medication. This should always also include a family history, especially with respect to parents, siblings and children, as it may influence the patient's condition both genetically and epigenetically. A social history may be of primary relevance as interpersonal, occupational, legal and financial matters may affect the symptom complex and the premises for the treatment. The patient's profession and hobbies may affect the timing and type of operation as well as selection of the implant type and fixation method. The use of habit-forming substances, such as alcohol and tobacco, is an essential part of the social history, as such patients tend to suffer more from postoperative complications.

In the physical examination, a comparison of the knees may provide important clues in the form of asymmetry, which may help detect subtle deformities and muscle atrophies. An inspection of the colour, temperature and state of the skin and hair of the knee, thigh and leg may reveal compromised arterial, venous or lymphatic circulation, which give a predisposition to slow healing and infectious complications. Wounds, scars and sinuses should be looked for as it might become necessary to treat them preoperatively. Eventual synovitis and hydrops as well as bony protuberosities of the knee joint should be checked. Wasting of the quadriceps and calf muscles may necessitate active physiotherapy and training. Genu recurvatum, genu valgus, genu varus or flexion deformity should be noted as they need to be corrected. Palpation of the margins of the joint, with the knee joint in different positions, helps to exactly locate joint tenderness to specific anatomical structures. The patella is gently moved sideways to determine any tethering. Palpation of the back of the knee may reveal a Baker's cyst. Eventual laxity of the collateral ligaments is best checked with the knee in about 20-30° flexion to prevent locking of the knee by the cruciate ligaments and the posterior capsule as occurs in full extension. McMurray's test helps to assess eventual meniscal bucket handle and other tears. The anterior cruciate ligament is tested for laxity in an anterior drawer test by pulling the upper tibia forward on the femoral condyles with the knee flexed to a right angle and or using a somewhat similar Lachman's test with the knee in about 20° flexion in a relaxed patient. The

pivot shift or jerk test is used to assist in the diagnosis of suspected ruptures of the anterior cruciate ligament. The laxity and integrity of the posterior cruciate ligament are tested by pushing the tibia backward on the femoral condyle in a posterior drawer test. The knees should be examined carefully and compared for their flexion and extension to record the full range of motion. Even healthy persons may have a slight degree of flexion or hyperextension deformity. Any tenderness in the strained extreme full extension or flexion of the knee should be noted.

A preoperative physical examination is important in revision total knee arthroplasty. Implants with appropriate varus/valgus constraint or rotating hinge components should be used after physical examination of the collateral ligaments to match their status and to avoid instability. A careful preoperative radiographic examination is necessary to decide whether primary (usually not enough) or revision implants, spacers or bone grafts will be needed to restore the joint line. The preoperative determination of the joint line position simplifies the surgery and facilitates flexion/extension space balancing. Because finding the appropriate joint line during surgery is difficult, the joint line position should be confirmed preoperatively. Gustke has defined the goal as being able to use the least constrained implants that will achieve stability (Gustke 2005). Unnecessary constraints strain implant-cement-bone interfaces and may accelerate peri-prosthetic osteolysis and loosening. After an appropriate preoperative examination and evaluation, it is possible to have at hand the components and equipment needed for a particular patient case.

2.7.2 Radiological

The quality of radiographs is essential in the evaluation of various compartments of the knee. The following routine radiographs are commonly used: 1) A weight-bearing anterior-posterior (AP) radiograph (14×17 inch cassette) that includes the shaft of the femur and tibia. If a long-stemmed component seems to be necessary, the isthmus, referring here to the minimum width of the bone medulla of the long bone, will be used to determine the appropriate stem size and its orientation. 2) A lateral radiograph (14×17 inch cassette) with the knee flexed to 90°. To obtain a true lateral radiograph, the ankle and the knee should be placed flat against the radiograph table and a tray should be used to ensure that the x-ray beams are perpendicular to the cassette to optimize the resolution of the radiograph. The posterior condyles of the femoral component should overlap. The knee should be rotated and repeat films obtained until the x-ray beams are perpendicular to the component. 3) If there is a history of a fracture or surgery to the ipsilateral extremity, it is prudent to obtain a full limb radiograph. 4) A sunrise view of the patella provides information about the condition of the patellofemoral joint, the patella and the extensor apparatus (Engh and Ammeen 1998).

To be practical in clinical use, the classification of bone defects must be easy to understand and remember. The classification should preferentially at the same time provide a rationale for the proper selection of specific treatment options. To address

these issues, Engh and co-workers (Engh and Ammeen 1999) established a bone defect classification system for femoral and tibial bone defects with three different categories: 1) A type 1 defect implies intact or almost intact metaphyseal bone with only minor bone defects that do not compromise the stability of a revision implant, 2) A type 2 defect implies damaged metaphyseal bone with loss of cancellous bone in the metaphyseal compartment of such size that it requires cement filling, augments or a bone graft during the revision surgery to restore a reasonable joint line level. Such type 2 bone defects may only occur in femoral condyles or tibia plateau and are then designated type 2A defects. If they occur in both femoral condyles and tibial plateau, they are designated type 2B defects. 3) A type 3 defect implies that a whole segement, a major portion of either femoral condyles or tibial plateau, of the metaphysis is lacking. These defects are occasionally associated with collateral or patellar ligament detachments and usually require long-stemmed revision implants and bone grafting or a custom-made or hinge implant in the revision surgery (Engh and Ammeen 1999).

2.7.3 Clinical and function scores

The Hospital for Special Surgery Rating System (HSS) (Insall et al. 1976) and the Knee Society Clinical Rating System (KSS) (Insall et al. 1989) are the two most widely used scoring systems for the evaluation of the outcome of knee arthroplasty. The KSS system was in part developed based on the older and already existing HSS scoring system.

The HSS system is widely used. It combines an evaluation of the operated knee and the patient's general function in one score, which is sometimes a bit problematic. If a patient has no pain and has an excellent range of motion in the operated knee, but cannot walk due to arthritis in the contralateral limb or for some other totally unrelated chronic medical problem, such as heart failure, the total score would be "artificially" low (Insall et al. 1976).

KSS has become the standard tool for the clinical evaluation and reporting of the results of TKA surgery. Most major journals in this field of study strongly encourage the use of the KSS score as an evaluation tool so that qualified information would be available on the outcome and to enable a comparison of different studies. The KSS system deals separately with the status of the operated knee and the function score of the patient, which solves the problem with interference by comorbid conditions. The Knee Score consists of scores for pain, range of motion and stability in both the coronal and sagittal planes, with deductions for fixed deformities and extensor lag. The Function Score consists of scores for the ability to walk on a level surface and to ascend and descend stairs, with deductions for the use of external supporting devices. These two subscales of KSS are usually recorded separately as two scores, the KSS Knee Score and KSS Function Score, rather than as one summation score.

At the time of planning the KSS, the Knee Society considered all the commonly used and already existing rating systems. It was concluded that the inclusion of the three main parameters reflecting the state of the knee, namely pain, stability and range of

motion, would suffice, and that flexion contracture, extension lag and misalignment should be dealt with as deductions. Thus, a well-aligned, pain-free knee with 125° of motion, and negligible antero-posterior and medio-lateral instability scores 100 points. Similarly, the simplified but practical KSS Function Score considers only walking distance and stair climbing, with deductions being made for walking aids. A patient, who can walk an unlimited distance and can normally go up and down stairs, receives the maximum score of 100. The form itself is largely self-explanatory: 50 points are alloted for pain, 25 for stability and 25 for range of motion. Walking ability is rated in approximately 100 metre blocks. Stair climbing is considered normal if the patient can ascend and descend stairs without holding onto a rail (Insall et al. 1989).

2.7.4 Radiological measurement

The Knee Society has also developed a Radiographic Evaluation system for knee radiographs (Ewald 1989), which takes several predefined parameters into account in the evaluation of TKA x-rays. The tibia is examined in the AP and lateral views, the femur in the lateral view and the patella in the skyline or Merchant view. These are described in some detail below.

In the AP view of the tibia, seven zones are delineated, but this is design-specific as, for example, zones 5, 6 and 7 are only used when the implant has a stem. The consensus decision reached in The Knee Society meeting of September 10, 1986, was that the number and location of the zones to be examined should be established by the prime developer of any particular knee implant design. An example of the zonal assignment of the interface of the tibial plateau is presented in Figure 4. In the lateral view of the femur, seven zones are evaluated, again with zones 5, 6 and 7 being reserved for stem(s) of any length or number. If the implant does not have a stem, zones 5, 6 and 7 are designated to the central area. An example of zone assignment for the femoral component in the lateral view is presented in Figure 4. The patella, viewed in skyline or in the Merchant view, has 3-5 zones among which 3, 4 and 5 can be used for the lug fixation, whether it is single or multiple (Figure 4).

The score for each of the three components of the total knee replacement implant system is determined by measuring the width of the radiolucent lines for each of the zones in millimetres. To obtain the total (sum) score for each component, the widths for each zone are added together. This procedure generates a single numerical score for each component. Five to seven zones may be assigned for the tibia and femur and three to five for the patella. These scores, for example for the seven-zone tibial component, can be rated as follows: ≤ 4 and nonprogressive is probably not significant; if the tibial implant scores 5-9 it should be closely followed for eventual progression; and if the tibial component score ≥ 10, a failure is possible or impending regardless of the symptoms (Ewald 1989).

For the mechanical axis of the knee and implant, the following angles are measured from the AP view, the femoral (α) and the tibial angle (β). The lateral view is used to measure the angle between the stem of the femoral component and femur (γ) and the

posterior slope of the tibial tray (δ) (Figure 4) (Ewald 1989).

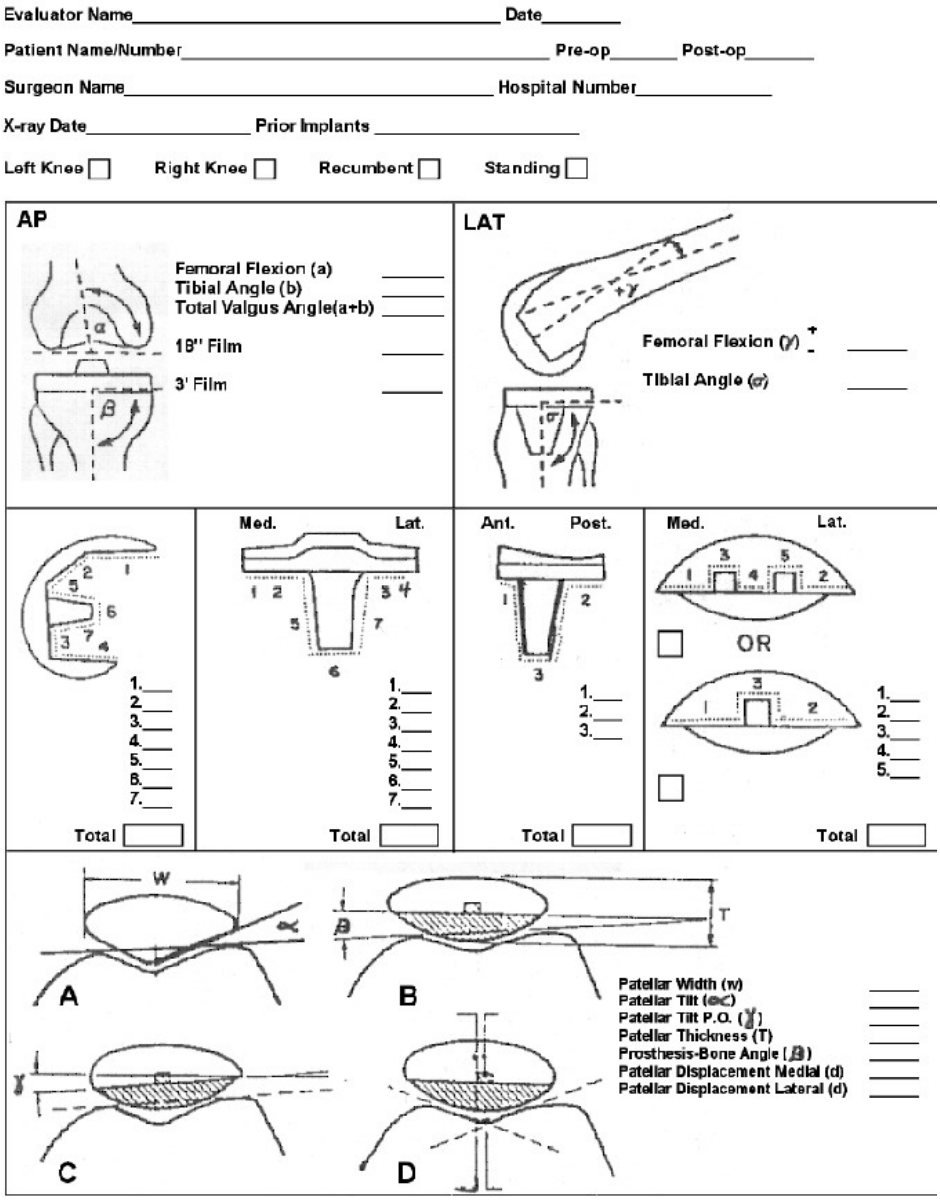

Figure 4. A schematic presentation of an implanted 3-part (total) human knee implant in the antero-posterior (AP) and lateral (LAT) view. The femoral component has 7 different zones in the lateral view, but some of these are design-specific as, for example, zones 5, 6 and 7 are only used when the component has a stem. The tibial component has 7 zones in the AP view, but some of these are again design-specific as, for example, zones 5, 6 and 7 are only used when the implant has a stem. The corresponding number of zones in the tibial component is only 3 in the lateral view. The patellar component viewed in skyline or in the Merchant view has, depending on its design, either 5 or 3 different zones. In addition, attention is paid to the position of the patellar component in relation to its femoral groove.

2.8 Clinical results

2.8.1 Register literature of revision TKA

1991 Vingard et al. reported a register-based primary TKA cohort study, which consisted of 250,217 people from a census in 1980. This study population was assessed for eventual hospital care provided for OA of the hip or knee during 1981-1983 by using a linkage of the Population Register to the Swedish Hospital Discharge Register. Their findings suggests that heavy physical work contributes to OA of the hip and knee (Vingard et al. 1991).

A series of reports based on the Swedish Knee Arthroplasty Register have been published (Knutson et al. 1994, Robertsson et al. 1997, Robertsson et al. 1999c, Robertsson et al. 1999b, Robertsson et al. 1999a, Robertsson et al. 2000b, Robertsson 2000, Robertsson et al. 2000a, Robertsson et al. 2000c, Robertsson et al. 2001, Robertsson and Ranstam 2003). Other reports described the outcome of hip and knee arthroplasties using data from the Norwegian Arthroplasty Register and the Finnish Arthroplasty Register (Paavolainen et al. 1991, Paavolainen et al. 1999, Furnes et al. 2002, Himanen et al. 2005). Recently, Rand et al. evaluated the factors that influence the durability of primary TKA using a relatively well characterized hospital cohort (Rand et al. 2003). Despitethe increasing medical and health economical importance of revision TKA surgery, no systematic analysis of already available published literature had been performed or no register studies with nationwide coverage had been published on the outcome of revision TKA when this thesis work was initiated.

2.8.2 Arthritis

Osteoarthritis and inflammatory arthritis are common chronic joint diseases leading to painful end-stage joint changes. Therefore, they form the most common indications for primary TKA. Further, for this natural reason, these patients are also most often subjected to revision TKA. Although the etiology of these two common diseases is unknown, they influence the structures of the joint differently. Osteoarthritis is mainly considered to represent a disease of the articular cartilage, which becomes thinned and degenerated. In addition, subchondral bone undergoes sclerosis and osteophytes are formed at the joint margins. Subchondral bone cysts may develop. In contrast, inflammatory arthritis is primarily characterized by synovitis and inflammatory joint effusion. Synovial tissue may attach and grow on the surface of and into the hyaline articular cartilage, forming pannus. Pannus seems to be able to erode the bone, leading to joint erosions which typically develop first in the joint margins and progress in a centripetal direction. Rheumatoid arthritis is characterized by rheumatoid factor and antibodies against cyclic citrullinated peptides, but the ‘seronegative’ arthritides do not have such autoantibodies. Some of them are characterized by tissue type HLA-B27, which gives a predisposition to chronic

seronegative spondylarthropathies and reactive arthritis. Subchondral bone sclerosis and osteophytes are not typical features of inflammatory arthritides unless a secondary osteoarthritis ensues; in contrast, rheumatoid arthritis is often characterized by juxta-articular osteoporosis. Seronegative arthritides may be characterized by new bone formation. Inflammatory arthritis is also particularly likely to lead to peri-articular changes, which impair joint stability and can lead to malpositions, impaired quality of bone and damage to soft tissue (Braunwald et al. 2001a, Braunwald et al. 2001b). Degenerative osteoarthritis is a joint disease, but inflammatory arthritides are considered to be systemic diseases with many extra-articular features, like rheumatoid nodules, pericarditis, amyloidosis, scleritis, iritis, and vasculitis, etc.

Friedman and Poss described revision TKA in OA patients in 1988, reporting the mechanisms of failure, the clinical evaluation of the painful TKA operated knee, the surgical planning and operative techniques and the overall results of revision TKA at that date (Friedman and Poss 1988). To assess the eventual effect of physical activity as a risk factor for revision TKA in OA patients, Jones and his co-workers performed a matched case-control study, which suggested that patient-reported physical activity did not increase the risk of revision arthroplasty (OR 0.99, 95% CI 0.99-1.01) in 17 female and 9 male patients, 47-85 years old. It was concluded that patients who undergo primary TKA, can be encouraged to remain physically active after TKA surgery (Jones et al. 2004). Many studies were accomplished on OA and RA patients and suggested that the early results were good (Rand and Bryan 1988, Hanssen and Rand 1988, Goldberg et al. 1988, Whiteside 1989, Friedman et al. 1990, Rosenberg et al. 1991, Rand 1991, Padgett et al. 1991, Whiteside 1993, Murray et al. 1994). More recently, even excellent results have been increasingly reported (Laskin and Ohnsorge 2005, Musil et al. 2005, Peters et al. 2005, Harwin 2006). These results and this encouraging trend suggest that, when correctly performed, even the revision TKA has a similar potential for an excellent outcome as the primary TKA operation,

2.8.3 Bone defect

In 1986, Dorr et al. descried the outcome in 24 knees with bone grafts for tibial defects at the time of primary or revision TKA after a follow-up of 3-6 years. Incorporation was observed in 22 knees over 6 months (Dorr et al. 1986). Tsahakis et al. reported their results on the use of allografts in the reconstruction of large uncontained bone defects in the femur or tibia in 19 revision TKA patients after an average follow-up of 2.1 years. The knee score improved from 29 to 87 and the function score from 35 to 85 points. It was concluded that at least in short-term follow-up, bulk allografts seemed to be effective in the reconstruction of uncontained bone defects in revision TKA (Tsahakis et al. 1994).

Morselized cancellous autografts or allografts have been shown to be highly successful in the management of small cavitary bone defects in revision TKA (Benjamin et al. 2001, Whiteside 1998), but structural allografts are often required for

the reconstruction of large, contained or uncontained osseous defects. Short-term and a few midterm analyses of revision TKA with various prosthesis systems, together with structural allografts used to repair the bone defects, have been reported (Mow and Wiedel 1996; Engh et al. 1997; Clatworthy et al. 2001; Dennis 2002; Hockman et al. 2005). Mow and Wiedel reported 15 patients who underwent structural allografting as part of the revision TKA. The follow-up averaged 47 months. All allografts healed to host bone and 13 showed evidence of true incorporation. There were no infections or fractures of the allografts. The average range of motion and knee score improved although four complications developed (Mow and Wiedel 1996). In a midterm report after 96.9 months, Clatworthy and co-workers reported 52 patients in whom 66 structural allografts had been used to reconstruct major osseous defects. The survivor rate of the allografts was 72% at 10 years. Twelve knees (23%) required repeat revision at a mean of 70.7 months. The allograft was retained in two of these revised cases (Clatworthy et al. 2001). In summary, although the complication rate and risk for re-revision seem to be relatively high, these studies suggest good overall results with high union rates of the structural bone allografts if rigid fixation is obtained.

3. AIMS OF THE PRESENT STUDY

1. To summarize the currently available world literature describing the outcome of revision total knee arthroplasty.
2. To analyze the predictors of the outcome of revision total knee arthroplasty using data from the Finnish Arthroplasty Register.
3. To compare the results of revision total knee arthroplasty in patients with inflammatory arthritis and osteoarthritis treated using Total Condylar III revision prostheses.
4. To evaluate the results of revision total knee arthroplasty in an inflammatory arthritis patient cohort treated using Total Condylar III revision prostheses.
5. To assess the results of revision total knee arthroplasty in patients with major bone defects using Total Condylar III revision prosthesis and structural bone allografts.

4. MATERIALS AND METHODS

4.1 Patient outcome following revision total knee arthroplasty: A literature analysis (study I)

4.1.1 Literature Search

A computerized literature search was performed using MEDLINE to identify all citations concerning revision total knee surgery published from 1.1.1990 through 31.8.2002 using the MeSH terms knee, prosthesis, arthroplasty, and revision. We obtained a copy of all original articles identified and written in English. Rreference lists of all retrieved review articles published during the same period from 1990 through 2002 were also examined for more eventual sources.

A multistage assessment was used to determine which articles contained data that could address our study questions. In the first stage, the study investigators determined the number of patients enrolled and whether the article reported on any postoperative outcomes. All articles that enrolled less than 10 subjects or failed to report any postoperative outcome and were published before 1990 were excluded. In the second stage, all articles that (1) reported knee surgery procedures other than revision total knee replacement or (2) did not report outcomes relevant to our research questions were excluded. In the third stage, all articles that used an outcome measure other than the global knee-rating scale were excluded. A global knee-rating scale was for this purpose defined as an instrument that measured pain, function and range of motion and combined these domains in a summary scale. This third filter of the identified literature was necessary to allow comparison of global outcomes across studies.

4.1.2 Data Abstraction

One investigator, who had been educated in data abstraction requirements, completed the data abstraction. Difficulties in abstracting data primarily resulted from two types of missing data. First, when an author did not mention the variable of interest in the article, the data abstracter could not be certain whether this particular characteristic had perhaps not been assessed at all or was simply not reported. Second, in some articles the variable of interest was mentioned as applying to a subset of enrolled patients, but the number of these patients and the eventual rules for their stratification were lacking.

Examples of variables that could not be included in the present study due to inconsistent reporting included the patients' race, prosthetic design, previous surgical procedures on the index knee and postoperative rehabilitation, etc.

In addition to missing data, two other problems relating to the reporting were encountered. It was not always quite clear if the author had reported data using the

patient or the knee as the unit of analysis. To correct this bias, the mean proportion of enrolled knees to enrolled patients was determined based on all studies that reported both, and then all data from these studies was converted to "patients" which was then used in the analysis. As most of the studies used the knees to report postoperative complications, complications were also reported using knees as the unit in the analysis. For the analysis of complications, "patients" were converted to "knees" if the data in the source report was only reported as patients. The other problem related to the authors' choice of the global knee rating system. To allow a comparison of patient outcomes across studies, the global knee rating scale score system, which evaluated the outcome of preoperative and postoperative state of the patients, was converted to a 100-point scale system corresponding to the Knee Society's Scoring System, the Hospital for Special Surgery knee rating scale system and the Bristol scale system. All different scoring systems were analyzed independently and separately.

Complications were reported in the source reports using a variety of styles. Some studies did not report complications that were of a minor nature, transient or not directly related to the prosthesis. To provide some consistency across studies in reported complication rates, such complications were not included in the complication rates, meaning that complications such as delayed wound healing, haematomas, knee effusions and pressure sores, etc., were excluded from the analysis.

Because of the high number of different prostheses used in different parts of the world and reported in the literature, and also due to the varying number of studies reporting on the use of a particular prosthesis, two classification schemes were created for the comparison of different prostheses. First, they were classified into three different subcategories based on the fate of the cruciate ligaments as 1) posterior cruciate ligament sparing, 2) posterior cruciate ligament sacrificing without posterior cruciate ligament substitution and 3) posterior cruciate ligament sacrificing and substituting prostheses. The second classification was based on the implant trademark. If the article reported data using more than one classification and stratified the patients and outcomes by using these classifications, this data was regarded as two separate reports. If an article reported data using more than one classification but did not stratify outcomes using such classifications, the article was regarded as a single report in which the outcomes formed a mixed group.

4.1.3 Data Analyses

One investigator, who is a professional statistician, completed the data analysis independently. A multivariate analysis was performed using the mean postoperative global knee score, function score and range of motion as dependent variables. Because individual studies had different sample sizes, these means were weighted by the number of enrolled patients. Only variables with significant bivariate relationships ($P < 0.05$) were included as independent variables.

4.2 Review of the Finnish arthroplasty register for revision total knee arthroplasty (study II)

4.2.1 Patient demographics

The database maintained by the Finnish Arthroplasty Registry was used as a source for records. Only records on first total knee revisions were included; repeat revisions were excluded.

The Finnish Arthroplasty Registry contained information on 2,845 revision total knee replacements performed from 1990 through 2002. Two hundred and eight of those procedures were repeat revisions, which were excluded from the study. The final number of knees analyzed was thus 2,637.

The mean age of the patients at the time of revision was sixty-nine years (range, seventeen to ninety-one years). The most common reasons for revision were loosening of the tibial component, the femoral component, or both components (33%) and patellar complications (32%) (Table1). The numbers of prostheses used in primary TKA were Anatomic Graduated Components (AGC) Dual Articular 267, AGC V2 242, Duracon 360, Duracon/Modular 190, Link Endo Modell 238, NexGen 157, Press Fit Condylar (P.F.C) Sigma 92.

Certain patient, disease, operation and implant characteristics are recorded in this registry and they form the basis for the factors, which can be analyzed as predictors for implant survival as summarized in Table 2. This enabled the study of the effect of age at revision operation, gender, diagnosis, year of first revision operation, time between previous operation and revision, reason for revision, type and brand of prosthesis, fixation method, usage of bone grafts, incidence of primary complications and type of operating hospital on the outcome.

Table 1. Patient demographics. All values refer to knees, except values for gender, which refer to patients.

Variable	Number of valid cases	%	(No.)
Age at revision (average = 69 yrs)	2637 /2637 (100%)		
≤ 55 yrs		9.6	(253)
56-70 yrs		39.5	(1041)
> 70 yrs		50.9	(1343)
Gender	2486 / 2486 (100%)		
Female		76.2	(1894)
Male		23.8	(592)
Diagnosis	2422 / 2637 (91.8%)		
Primary osteoarthritis		76.6	(1855)
Secondary osteoarthritis		4.1	(99)
Rheumatoid arthritis		16.5	(399)
Other arthritis		1.1	(26)
Other illness		1.8	(43)
Reason for revision	2443 / 2637 (92.6%)		
Loosening, tibial component		16.8	(410)
Loosening, femoral component		4.8	(118)
Loosening, both components		10.9	(267)
Infection		4.7	(115)
Patellar luxation		3.8	(94)
Malposition of prosthesis		11.3	(277)
Fracture of bone		2.1	(52)
Fracture of prosthesis		8.3	(203)
Patellar complication		31.7	(775)
Other		5.4	(132)
Any primary complications	2637 / 2637 (100%)		
No		96.2	(2536)
Yes		3.8	(101)
Type of prosthesis	2371 / 2637 (89.9%)		
Hinged		20.0	(474)
Condylar		80.0	(1897)
Fixation	1897 / 2637 (71.9%)		
Cementless		3.8	(73)
Hybrid		2.2	(41)
Cemented		94.0	(1783)
Bone graft	2637 / 2637 (100%)		
Used		11.0	(2347)
Not used		89.0	(290)
Time between previous operation and revision	2607 / 2637 (98.9%)		
< 5 yrs		44.9	(1171)
≥ 5 yrs		55.1	(1436)

Year of first revision	2637 / 2637 (100%)		
1990-1995		31.0	(817)
1996-2002		69.0	(1820)

Table 2. Factors included in the statistical analyses.

Factor	Groups
Age at revision operation	≤ 55
	56-70
	> 70
Gender	male
	female
Diagnosis	rheumatoid arthritis
	osteoarthritis (primary or secondary)
Year of first revision operation	1990-1995
	1996-2002
Time between primary and revision operation	< 5 years
	≥ 5 years
Reason for revision	loosening (femoral component, tibial component or both) infection
	patellar luxation
	malposition of prosthesis
	fracture of prosthesis
	patellar complication
	other reason
Type of prosthesis	hinged
	condylar
Brand of prosthesis	AGC Dual Articular
	AGC V2
	Duracon
	Duracon Modular
	P.F.C. Sigma
	Nexgen
	Link Endo-Modell
Fixation method	cementless
	hybrid
	cemented
Usage of bone grafts	Used
	not used
Primary complications	any complication
	no complications
Type of operating hospital	university hospital
	central hospital
	regional hospital
	other

4.2.2 Statistical analyses

Data was analyzed with SPSS statistical software (version 12.0.1; SPSS, Chicago, Illinois). Variable descriptives were checked to find any extreme values or errors in data input. Categorical variables were dummy-coded. For the survival analyses, the original data file from the National Implant Registry was organized so that each row represented one knee. The steps in the analysis included checking the adequacy of the proportional hazards (the probability of an end event) assumption by graphical examination of the partial residuals and, more formally, by testing the significance of time dependency (a trend in the partial residuals with time and significance of the time-dependent covariate [that is, an interaction term between the covariate and time] were taken as evidence against the assumption), testing for significant differences in survival with use of Kaplan-Meier survivorship analysis and log-rank tests, calculating univariate statistics for each variable, entering significant variables into a multivariate Cox model, and using Cox regression model diagnostics in order to determine whether the model adequately described the data. In addition to the analysis of the proportional hazards assumption, as detailed above, model diagnostics included checking for influential observations (Fox , 2002). In order to detect any exceptionally influential observations or outliers, dfbeta values, which estimate changes in the regression coefficients on deletion of each observation in turn, were calculated.

The significance level (p value) was set at 0.05 for all statistical testing. However, weakly significant variables ($p < 0.1$) were also included in the multivariate Cox model.

The results are given as the mean and 95% confidence interval if not otherwise indicated. Binomial confidence intervals were calculated for the survival figures with use of Clinstat (Bland, 2000.).

4.3 Revision total knee arthroplasty with the Total Condylar III revision prosthesis system (studies III-IV-V)

4.3.1 Patients

The individual Social Security Numbers of Finnish citizens who had undergone revision TKA at Tampere University Hospital until the end of the year 2000, were collected from the Hospital Patient Database. Preoperative, operative and follow-up data had been collected and saved into a database specially designed for the follow-up of joint replacement operations. In addition, structured follow-up forms of physiotherapists are recorded in this database and were used for these studies focusing on TC III revision prosthesis. The date of the primary TKA and the type of the implanted prosthesis were confirmed from the Finnish Arthroplasty Register maintained by the National Agency of Medicines (Nevalainen J, 2003). The National Arthroplasty Register was also used to make certain that none of the patients in the

current series had had any re-revision arthroplasties in hospitals other than Tampere University Hospital or Coxa (a hospital for joint replacement, which assumed responsibility for total joint replacements in the Pirkanmaa Hospital District in September 2002).

Between 1994 and 2000, 71 revision TKA had been performed in Tampere University Hospital for 69 patients using the TC III system. These revisions comprised 56 knees in women and 15 knees in men, with the mean age of 69.1 years (range 36-85). The patients were also followed up for 70.7 months (range 36-122) after revision surgery from data files in the National Arthroplasty Register. The reason for this operation was inflammatory arthritis in 16 knees and OA in 55 knees.

The time interval between the primary and revision arthroplasty was on average 6.8 years. The main reasons for the revision operation were instability (n = 41), polyethylene wear (n = 26) and aseptic loosening (n =17). In some cases more than one reason for revision was recorded, such as polyethylene wear and aseptic loosening with instability. The brands of the removed prostheses were Anatomic Graduated Components (AGC) (n = 9), Anametric (n = 1), Duracon (n = 11), Miller-Galante (n = 2), Press Fit Condylar (PFC) (n = 2), TC III (n = 1), Porous Coated Anatomic (PCA) (n = 9), PCA Modular (n = 16), Townley Synatomic (n = 15) and Townley (n = 5). Thus, the series comprised 25 cases with PCA or PCA modular and 20 cases with Townley or Townley Synatomic. Two cases were treated using wedges and 10 cases with structural bone allograft, 8 for bone defects and 2 to restore alignment. Three of the structural bone allografts were used in patients with inflammatory arthritis and seven in patients with OA.

Two experienced senior orthopaedic surgeons (Jorma Pajamäki and Pekka Halonen) performed all revision operations except two, in which cases also the Larsen grade had not been recorded before the primary TKA. In all operations, with one exception, stemmed TC III components were used and fixed with cement. The patella was resurfaced in 35 cases. Cefuroxime was used as the prophylactic antibiotic in the revision operations. Antibiotic-impregnated cement was used in those revisions performed for prosthetic infections. Five of the eight revisions performed for infections were done in two stages.

Inflammatory arthritis had been diagnosed in 13 knees in women and 3 in men. The mean age of these patients was 59 (range 36-78) years at the time of revision surgery. The mean weight of the patients was 69 (range 47–96) kg. The patients were followed for 74 months after revision surgery (range 44-122). The mean duration of the disease was 27 (range 12–48) years. Twelve of the patients had RA, but one had juvenile chronic arthritis (both knees had been operated), one psoriatic arthritis, and one ankylosing spondylitis. The Larsen grade (Larsen, 1977) for knee destruction was Larsen grade 3 in 3 cases, grade 4 in 5 cases, and grade 5 in 6 cases before the primary TKA, but had not been assessed or reported in 2 cases. The reasons for revision were aseptic loosening (4 cases), instability (3 cases), polyethylene wear (3 cases), luxation of the patella (2 cases), infection (2 cases), periprosthetic fracture (1 case) or osteolysis (1 case). In the revision surgery, the prostheses removed were 6

PCA, 2 AGC, 5 Townley or Townley Synatomic, 1 Anametric, 1 Miller-Galante and 1 PFC. Cement fixation had been used in all, and there were various combinations of prostheses with and without stems. In the revision operation, all the components were fixed using cement. The method of fixation of the stems varied and both cementless press-fit and cemented stems were used. In 8 cases the patella was resurfaced and in the remaining 8 cases it remained untouched.

In the series of patients with major bone defects, 10 revision TKA operations were performed using the TC III revision prosthesis system in 10 patients, 9 women and 1 man. The mean age of the patients at revision surgery was 70 (range 61-77) years. Their mean weight was 80 kg (range 67-100). The patients were followed for 5 years after revision surgery (range 1-8), except for one patient who died one year after the follow-up visit. The remaining patients were followed up for more than 3 years. 7 patients had OA and 3 had RA. The reasons for revisions were osteolysis (7 cases), aseptic loosening (4 cases), polyethylene wear (4 cases), instability (2 cases), periprosthetic fracture (1 case) and malposition (1 case), with 5 patients having more than one reason for revision. In the revision surgery, 7 Townley Synatomic, 1 PCA, 1 AGC and 1 PFC prostheses were removed. Eight patients had massive bone defects in the femoral side and nine patients in the tibia. Three patients had only femoral or tibial side involvement.

4.3.2 Operative technique for the use of structural allografts

After removal of the prostheses, the bone defects were classified. It often appeared that the actual sizes of the defects were larger than had been apparent from the preoperative radiographs. The use of allogenous femoral head grafts was necessary in all 10 cases. Allografts were collected in elective total hip replacements from voluntary patients whose suitability to provide bone was ensured using a strict safety protocol. Grafts were stored in sterile bags in the local bone bank at -70 °C. For use in the revision operation, they were transported in dry ice to the operating theatre where they were slowly warmed in an NaCl solution. For the insertion of the allografts, the following technique was used for both the femoral and tibial side. The host recipient site for the femoral head allograft was cleaned with acetabular reamers free from granulomatous and fibrous tissue. The bone bed was prepared until viable cancellous bone was reached and then until a hemispherical shape was created to provide optimal containment and stability for the graft, but without destroying the ligamentous attachments in the condyles or at the tibial plateau. A vice system for holding bone was used to stabilize the femoral-head allograft on a separate table during preparation of the graft. Femoral-head shapers (Allogrip, DePuy, Warsaw, IN, USA) were used to remove cartilage and subchondral bone plates before reaming down to the cancellous bone, with the aim being to use 1-2 mm oversized grafts. The graft prepared was impacted into the complementary recipient site and temporarily stabilized using Kirschner wires. The graft was trimmed to accept the respective cutting guides for the preparation of the tibia or femur. In three cases a vitallium screw, and in one case a Kirschner wire, was used as additional fixation to ensure good permanent stability of

the graft. Morsellized autologous or allogenous bone was used to fill minor defects and around the structural graft to promote graft-bone integration. Using trial components the graft was placed in the graft bed. The stability of the knee was confirmed in flexion and the length of the graft adjusted to achieve correct position and soft tissue balance. After this the cemented modular TC III prosthesis was implanted. Both components used contained stems in all cases. Cemented stems were used if there were no bone defects on the femoral or tibial side or when the host bone was osteoporotic and the cortical bone was thin. Otherwise uncemented fluted extensions were used, as in the case of major bone defects where they provide horizontal and rotational stability but allow minor subsidence and stress towards the condyle containing allograft bone. In six cases both the femoral and tibial stems were cementless (press-fit) and in one case they were both cemented. In the remaining three cases, a combination of a cemented stem and a press-fit stem was used. In 5 cases the patella was resurfaced and in the remaining 5 cases it remained untouched. Finally, the wound was closed according to routine protocol. After knee revision, including structural allografting for a bone defect, it was almost always possible to let the patient go fully weight-bearing, as the remaining intact part of the condyle can stand the stress.

4.3.3 Clinical and radiological follow-up

Patients were examined before revision, during hospitalization and at the outpatient clinic 2 months postoperatively, with further follow-up visits scheduled 1, 3, 5 and 8 years after the operation according to a predefined schedule. All examinations included clinical and radiological evaluation according to the prevailing routine follow-up regime, weight-bearing radiographs were obtained in every instance both pre-operatively and postoperatively, but full limb radiographs were taken only pre-operatively. Clinical assessment was performed using the Knee Society Clinical Rating System (Insall et al. 1989). An 85-100 point score is considered to represent excellent, 85-70 points good, 69-60 points fair and < 60 points a poor result. Anterior-posterior (AP) and lateral radiographs of the knee were taken with the patient standing and evaluated using the Knee Society Rating System (Ewald, 1989). The distance from the centre of the tibial component to the centre of the tibia in the AP view (tibial tray shift) and the distance from the centre of the tibial component to the centre of tibia in lateral view (tibial tray shift) were measured.

Bone defects in the femoral and tibial side were classified according to the Anderson Orthopaedic Research Institute bone defect classification guidelines (Engh and Ammeen, 1999). The three end-points of the bone allograft study were (i) death, (ii) removal or revision of the prosthesis or (iii) amputation of the limb.

4.3.4 Statistical analysis

The Kaplan-Meier analysis was used for survivorship analysis. All data was checked

for normality using Wilk's W test. Comparisons between the pre- and postoperative values were done using SPSS 12.0 and paired *t*-test for normally distributed and the *Chi-Square* test or Wilcoxon's test for skewed data. Probability values < 0.05 were considered statistically significant.

5. RESULTS

5.1 Patient outcome following revision total knee arthroplasty (study I)

5.1.1 Literature Description

605 articles were identified in the literature search from 1990 through 2002, and 33 of these studies passed through all three filters reporting patient outcomes following revision TKA (Table 3). 42.4% of these articles had been published in Clinical Orthopaedics and Related Research and 36.4% in the Journal of Arthroplasty. Four studies reported stratified results across two different prosthetic classifications, and one reported stratified results across three different prosthetic classifications in 33 patients. The Knee Society score system was used in 70% of the studies.

Table 3. 33 articles filtered out of 605 in the literature search covering a period from 1990 to 2002 and reporting patient outcomes following revision total knee arthroplasty.

Author	Origin	No: of revisions (knee)	System of score
Babis GC	JBJS (Am). 2002, 84(1): 64-68	56	KSS
Barrack RL	J Arthroplasty. 2000, 15(4): 413-417	73	KSS
Barrack RL	J Arthroplasty. 2000, 15(7): 858-866	103	KSS
Benjamin J	Clin Orthrop. 2001, 392: 62-67	46	KSS
Berry DJ	Clin Orthop. 1993, 286: 110-115.	42	KSS
Bohm I	J Arthroplasty. 2000, 15(8): 982-989	35	HSS
Bradley GW	Clin Orthop. 2000, 371: 113-118.	21	KSS
Bugbee WD	J Arthroplasty. 2001, 16 (5): 581-585.	139	KSS
Chakrabarty G	J Arthroplasty. 1998, 13(2): 191-196	73	Bristol
Christensen CP	J Arthroplasty. 2002, 17 (4): 409-415.	11	KSS
Clatworthy MG	JBJS (Am). 2001, 83(3): 404-411	52	HSS
Elia EA	Clin Orthop. 1991, 271: 114-121	40	KSS
Fehring TK	Clin Orthop. 1998, 356: 34-38.	63	HSS
Ghazavi MT	JBJS (Am). 1997, 79(1): 17-25	30	HSS
Gill T	Clin Orthop. 1995, 321: 10-18	30	KSS
Haas SB	JBJS (Am). 1995, 77(11): 1700-1707.	76	HSS
Hartford JN	J Arthroplasty. 1998, 13(4): 380-387	16	KSS
Hohl WM	Clin Orthop. 1991, 273: 91-97	29	KSS
Ikezawa Y	J Orthop Sci. 1999, 4: 83-88	23	KSS
Karbowski A	Arch Orthop Trauma Surg. 1998, 117: 256-258	36	HSS
Knight JL	J Arthroplasty. 1995, 10(6): 748-757	18	HSS
McAuley JP	Clin Orthop. 2001, 392: 279-282	32	KSS
Mow CS	Clin Orthop. 1994, 309: 110-115.	17	KSS
Mow CS	J Arthroplasty. 1998, 13(6): 681-686	36	HSS
Mow CS	J Arthroplasty. 1996, 11(3): 235-241	16	HSS

Murray PB	Clin Orthop. 1994, 309: 116-123	40	KSS
Otte KS	J Arthroplasty. 1997, 12(1): 55-59	29	HSS
Padgett DE	JBJS (Am). 1991, 73(2): 186-190	21	HSS
Peters CL	J Arthroplasty. 1997, 12(8): 896-903	57	HSS
Rosenberg AG	Clin Orthop. 1991, 273: 83-90	36	HSS
Takahashi Y	Clin Orthop. 1994, 309: 156-162.	39	KSS
Tsahakis PJ	Clin Orthop. 1994, 303: 86-94	19	KSS
Whiteside LA	Clin Orthop. 1998, 357: 149-156	63	KSS

KSS=Knee Society Score for clinical rating HSS=Hospital for Special Surgery knee score for clinical rating

5.1.2 Patient Characteristics

The number of patients in these 33 studies was 1,356. Some articles lacked information on the gender of the patients（Barrack et al, 2000b, Benjamin et al, 2001, Fehring and Griffin, 1998, Hartford et al, 1998, Hohl et al, 1991, Karbowski et al, 1998, Knight et al, 1995）, but those reporting it contained 429 men and 611 women with the weighted mean age 67 years (range 45 to 90 years). The studies reported the outcomes of a mean of 41 patients (median value 34 patients). The weighted mean patient follow-up time was 57 months (median 48 months, range 6-108 months).

5.1.3 Study Outcomes

The weighted mean preoperative and postoperative global knee scores were 49 (range 15 to 82) and 84 (range 58 to 109), respectively. The weighted mean preoperative and postoperative ranges of motion were 83° (range 32-134°) and 95° (range 51-139°) respectively. The mean preoperative and postoperative function scores were 36 (range 0-75) and 59 (range 19-100). The results show that the differences between the pre- and post-operative Knee score, Function score and Motion Score values were significant (Knee score: $t=12.507$, $p < 0.001$, Function score: $t=4.704$, $p < 0.001$, Motion score: $t=5.346$, $p < 0.001$).

5.1.4 Prosthesis Characteristics

Two graphs were constructed to display the type of the prostheses according to an anatomic and brand name classification. In the group classified according to posterior ligament anatomy, posterior ligament sacrificing and substituting (52%) and posterior ligament sparing (42%) were most commonly used. In the group classified according to the trade name (brand of the implant), the Insall-Burstein (Zimmer, 18%), TC III (Zimmer and J&J, 17%), Coordinate (Depuy, 16%), PCA (Howmedica, 16%) and PFC (J&J, 14%), were most popular. Many studies used mixed classifications, so these two categories could not always be separated unanimously. The differences between the implant categories reported during 1990-2002 were not statistically

significant.

5.1.5 The indication for revision

According to the literature analysis, loosening (55%) was the main reason for revision total knee arthroplasty, with polyethylene wear (11%), instability (10%), infection (7%) and progression of the basic disease (4%) representing other important reasons for revision.

5.1.6 Complications after revision surgery

The most common complications of revision total knee arthroplasties were loosening (18%), instability (16%) and infection (16%). Other complications included patellar failure (15%), pain of unknown origin (13%), and fracture (9%), migration (7%) and stiffness (6%). The patellar failures included patellar subluxations, patellar dislocations, patellar tendon avulsions, patellofemoral pain syndromes and patellar clunks.

5.2 Review of the Finnish arthroplasty register for revision total knee arthroplasty (study II)

5.2.1 Proportional hazards assumption

The proportional hazards assumption was met for age group, gender, diagnosis, time-interval between the primary and revision operations, year of first revision, reason for revision, type of implanted prosthesis, brand of prosthesis, use of bone grafts, primary complications, and fixation method. In other words, the hazards (the risks of repeat revision) associated with these variables did not depend on time. The proportional hazards assumption was not met for the type of hospital (university, central, regional, or other); the hazards associated with different types of hospitals varied over time.

5.2.2 Log-Rank tests and Kaplan-Meier survival analysis

The log-rank tests indicated that the diagnosis, type of implanted prosthesis, primary complications and type of hospital did not affect the survival of the revision total knee replacements. These variables were excluded from the multivariate Cox analysis. Age group, year of first revision operation, time between the primary and revision operation, reason for revision, brand of prosthesis, fixation method, use of bone grafts, and to a lesser extent gender ($p = 0.07$) were found to significantly affect the survival of the revision total knee replacements. These variables were included in the multivariate Cox analysis.

5.2.3 Univariate analyses

Prosthetic survivorship was estimated using the Kaplan-Meier technique, and hazard ratios were estimated by univariate Cox analyses (Table 4). The overall survival of the revision prostheses, with repeat revision as the end point, was 95% (95% confidence interval, 94% to 96%) at two years (1,874 knees), 89% (95% confidence interval, 88% to 90%) at five years (944 knees), and 79% (95% confidence interval, 78% to 81%) at ten years (141 knees) (Figure 5).

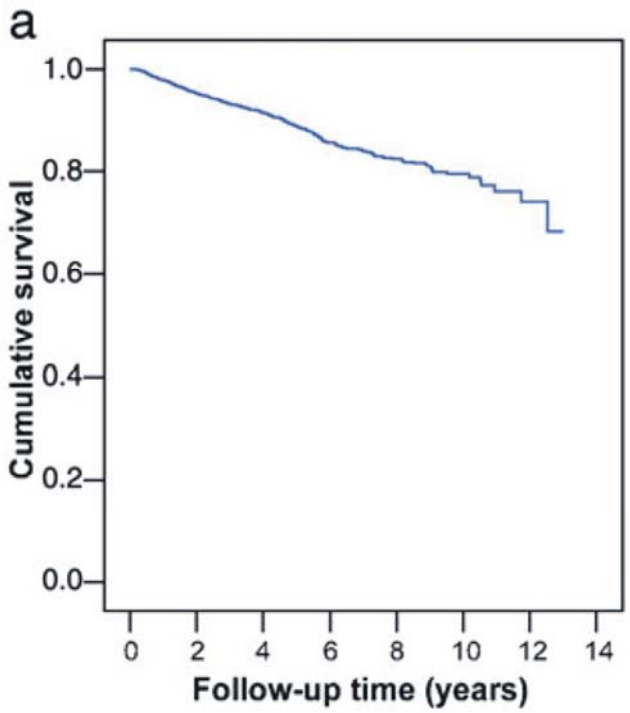

Figure 5. Overall cumulative survival as a function of time in years for revision total knee arthroplasty implants. In this analysis revision of the revision TKA implants, not loosening *per se*, was used as the end point.

Table 4. Estimated hazard ratios in uni- and multivariate Cox analyses.

Factor	Univariate analysis			Multivariate analysis		
	Hazard ratio	95% CI for hazard ratio	p-value	Hazard ratio	95 % CI for hazard ratio	p-value
Age						
(compared with ≤ 55)						
56-70	0.87*	0.61 – 1.24	0.45	0.91*	0.63 – 1.32	0.62
> 70	0.52*	0.36 – 0.76	**< 0.005**	0.55*	0.37 – 0.82	**< 0.005**
Gender						
(compared with male)						
female	0.77	0.59 – 1.02	0.07	0.80	0.60 – 1.07	0.13
Diagnosis						
(compared with RA)				Not included in multivariate analysis (not significant in univariate analysis)		
arthrosis (primary or secondary)	0.85	0.63 – 1.16	0.31			
Year of first revision operation						
(compared with 1990-1995						
1996-2002)	0.56*	0.43 – 0.72	**< 0.0005**	0.67*	0.50 – 0.90	**< 0.01**
Time between previous operation and revision						
(compared with < 5 years						
≥ 5 years)	0.52*	0.41 – 0.67	**< 0.0005**	0.62*	0.47 – 0.82	**< 0.005**
Reason for revision						
(compared to the overall effect)						
infection	1.10	0.66 – 1.85	0.71	0.79	0.46 – 1.36	0.39
luxation	2.00	1.26 – 3.16	**< 0.005**	1.86	1.16 – 3.00	**< 0.05**
malposition of prosthesis	1.23	0.85 – 1.77	0.28	1.17	0.81 – 1.71	0.40
fracture of prosthesis	0.71	0.43 – 1.17	0.18	0.85	0.51 – 1.41	0.52
patellar complication	1.22	0.93 – 1.61	0.15	1.29	0.97 – 1.71	0.08
loosening (any or both components)	1.22	0.95 – 1.58	0.12	1.23	0.94 – 1.61	0.13
Type of implanted prosthesis						
(compared with hinged)				Not included in multivariate analysis (not significant in univariate analysis)		
condylar	1.18	0.86 – 1.62	0.32			
Brand of prosthesis						
(compared with Duracon)				Not included in multivariate analysis because of missing values		
AGC Dual Articular	0.57	0.31 – 1.02	0.06			
AGC V2	0.87	0.52 – 1.44	0.58			
Nexgen	0.20	0.05 – 0.81	**< 0.05**			
Duracon Modular	0.34	0.12 – 0.95	**< 0.05**			
Link Endo-Modell	0.62	0.35 – 1.10	0.10			
P.F.C. Sigma	0.19	0.03 – 1.41	0.11			
Fixation						

(compared with cementless)				Not included in multivariate analysis because of missing values		
hybrid	0.90*	0.41 – 1.97	0.79			
cemented	0.48*	0.30 – 0.77	**< 0.005**			
Useage of bone grafts						
(compared with not used)						
Used	0.56	0.31 – 1.00	**0.05**	0.92	0.50 – 1.70	0.79
Primary complications						
(compared with no)				Not included in multivariate analysis (not significant in univariate analysis)		
Yes	1.09	0.64 – 1.88	0.75			
Type of operating hospital						
(compared with other)				Not included in multivariate analysis (not significant in univariate analysis)		
central	1.08	0.76 – 1.52	0.68			
regional	1.21	0.83 – 1.77	0.32			
university	1.08	0.79 – 1.47	0.65			

*) non-proportional hazards, hazard ratio is not constant

Prosthetic survival at five years, with repeat revision as the end-point, was 82% (95% confidence interval, 78% to 87%) for patients younger than fifty-six years of age, 87% (95% confidence interval, 84% to 89%) for those between the ages of fifty-six and seventy years, and 92% (95% confidence interval, 90% to 94%) for those older than seventy years of age. Prosthetic survival was significantly better for the patients older than seventy years than it was for the patients younger than seventy years ($p < 0.005$). However, it was not better for the patients between the ages of fifty-six and seventy years than it was for those younger than fifty-six years (Figure 6).

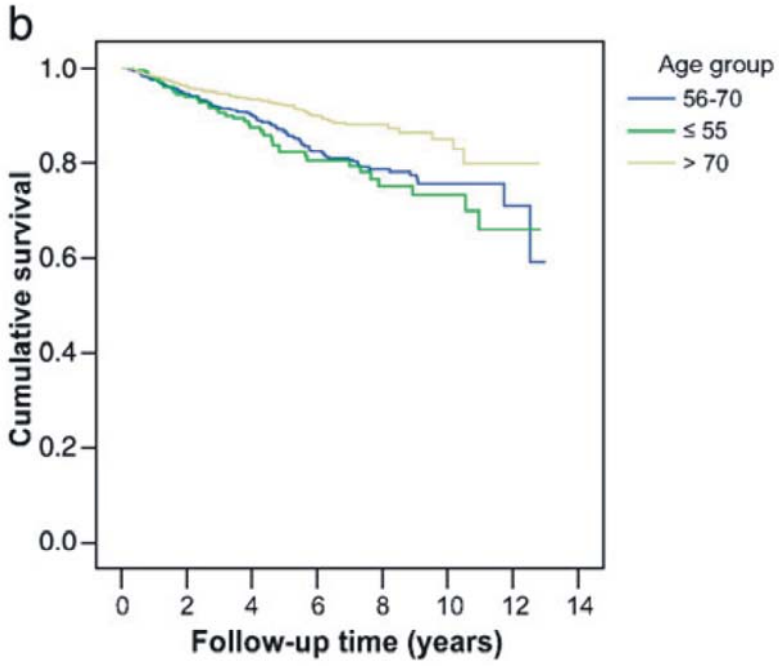

Figure 6. Cumulative survival as a function of time in years for revision total knee arthroplasty implants in three different age groups (groups compared against each other are "< 56 years", "56-70 years" and "> 70 years"). Revision of the rTKA was used as the end point.

Prosthetic survival at five years, with repeat revision as the end-point, was 84% (95% confidence interval, 81% to 87%) for men and 90% (95% confidence interval, 88% to 91%) for women ($p = 0.07$). The five-year survival rate was significantly worse ($p < 0.0005$) for patients who had had their first revision operation between 1990 and 1995 (85%; 95% confidence interval, 84% to 87%) than it was for patients who had had their first revision between 1996 and 2002 (92%; 95% confidence interval, 91% to 94%) (Figure 7).

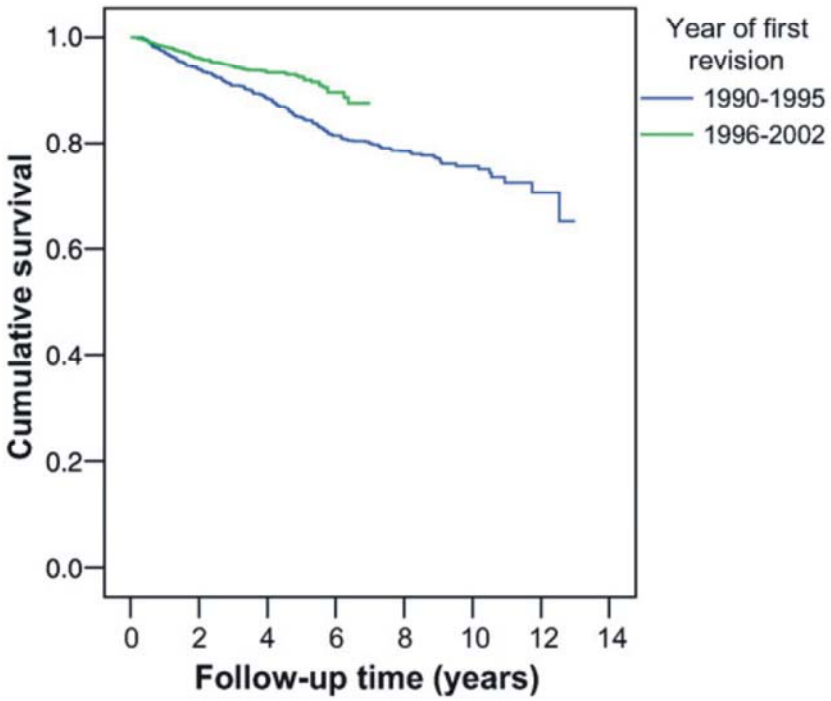

Figure 7. Cumulative survival of revision total knee arthroplasty implants according to the period of the first revision. The first revisions were divided into those performed between 1990 and 1995 (group "1990-1995") and compared to those in whom the first revision was performed later, between 1996 and 2002 (group "1996-2002"). The revision of the rTKA was used as the end-point.

Similarly, the survival rate following the revision arthroplasties performed less than five years after the primary operation (85%; 95% confidence interval, 83% to 87%) was significantly lower ($p < 0.0005$) than the rate following the revisions performed five years or more after the primary operation (92%; 95% confidence interval, 91% to 94%) (Figure 8).

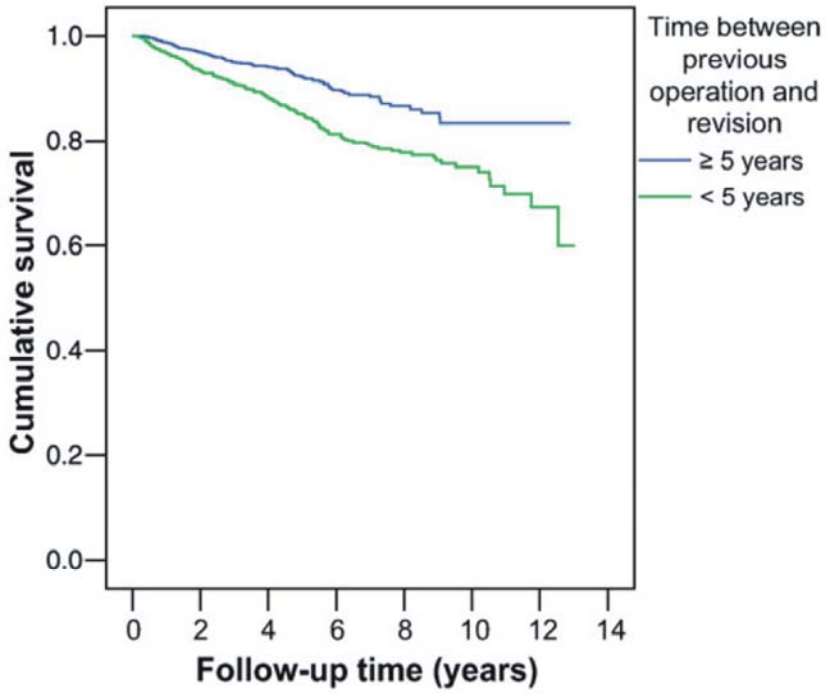

Figure 8. Cumulative survival of revision total knee arthroplasty implants in those patients in whom the primary TKA lasted for less than five years(group "< 5 years") compared to those, in whom it lasted for longer than five years(group "> 5 years"), i.e. according to the time between the primary and revision TKA. Revision of the rTKA was used as the end-point.

The survival of revisions done in patients with patellar subluxation was worse ($p < 0.005$) than the overall survival of revisions performed for other reasons (Figure 9).

Pairwise comparisons with use of the log-rank test indicated that the survival of revisions done because of subluxation differed significantly from that of revisions performed because of a fracture of the prosthesis ($p < 0.005$), but did not differ significantly from the survival of revisions due to loosening, malposition, infection, or other patellar complications.

The five-year survival rate, with repeat revision as the end-point, was 93% (95% confidence interval, 88% to 95%) for the AGC Dual Articular prosthesis (Biomet Merck Inc., Bridgend, UK), 90% (95% confidence interval, 84% to 93%) for the AGC V2 prosthesis (Biomet), 87% (95% confidence interval, 83% to 90%) for the Duracon prosthesis (Stryker Howmedica Osteonics, Allendale, New Jersey), 98% (95% confidence interval, 96% to 99%) for the Duracon Modular prosthesis (Stryker Howmedica Osteonics), 89% (95% confidence interval, 85% to 93%) for the Link Endo-Modell prosthesis (Waldemar Link, Hamburg, Germany), and 98% (95% confidence interval, 94% to 100%) for the NexGen prosthesis (Zimmer, Warsaw, Indiana) (survival curves not shown). No patient in the registry had had a P.F.C. Sigma prosthesis (DePuy Orthopaedics, Warsaw, Indiana) for five years, but the survival rate of that prosthesis at 4.5 years was 98% (95% confidence interval, 93% to 99%). The NexGen and Duracon Modular prostheses had better survival rates ($p < 0.05$) than the Duracon implant, which had the shortest time-to-event survival.

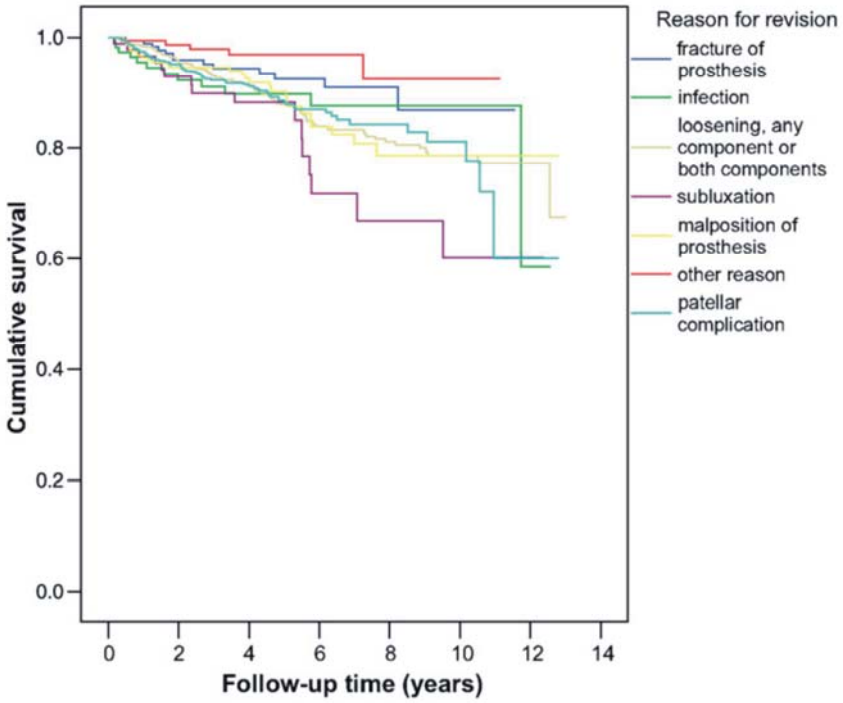

Figure 9. Cumulative survival of revision total knee arthroplasty compared in different sub-populations based on the reason (indication) for re-revision. The groups compared against each other are "Fracture of prosthesis", "Infection", "loosening, any component or both components", "subluxation", "malposition of prosthesis", "other reason" or "patellar complication". Revision of the rTKA was used as the end-point.

Cement fixation ($p < 0.005$, Figure 10) and bone-grafting ($p = 0.05$, Figure 11) improved prosthetic survival, whereas hybrid fixation did not differ significantly from cementless fixation with regard to prosthetic survival

The diagnosis, type of prosthesis, primary complications, and type of hospital did not significantly affect prosthetic survival.

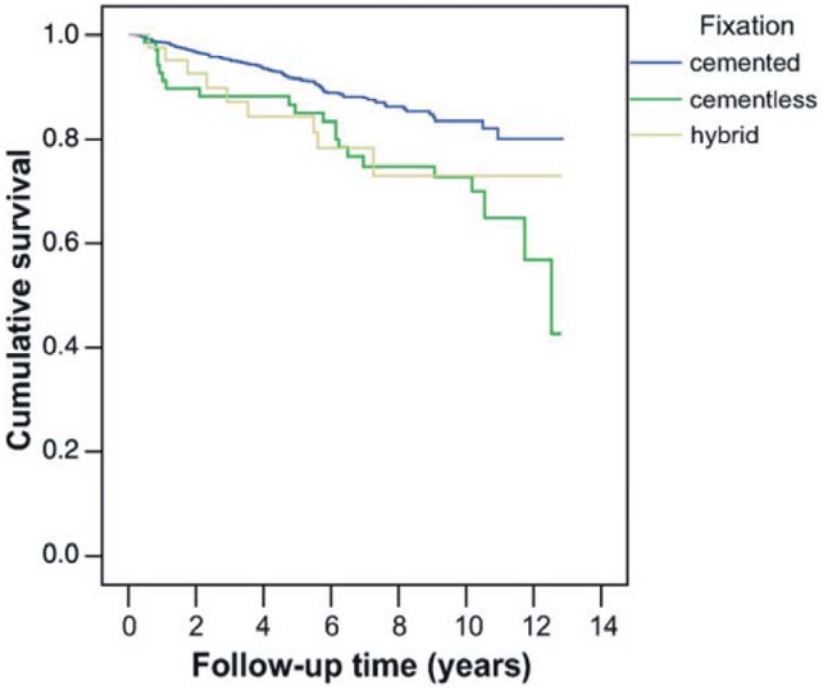

Figure 10. Cumulative survival of revision total knee arthroplasty implants based on the use of cement for fixation. Cement was used for the fixation of both components (group "cemented"), one component only (group "hybrid") or was not used at all (group "cementless"). Revision of the rTKA was used as the end-point.

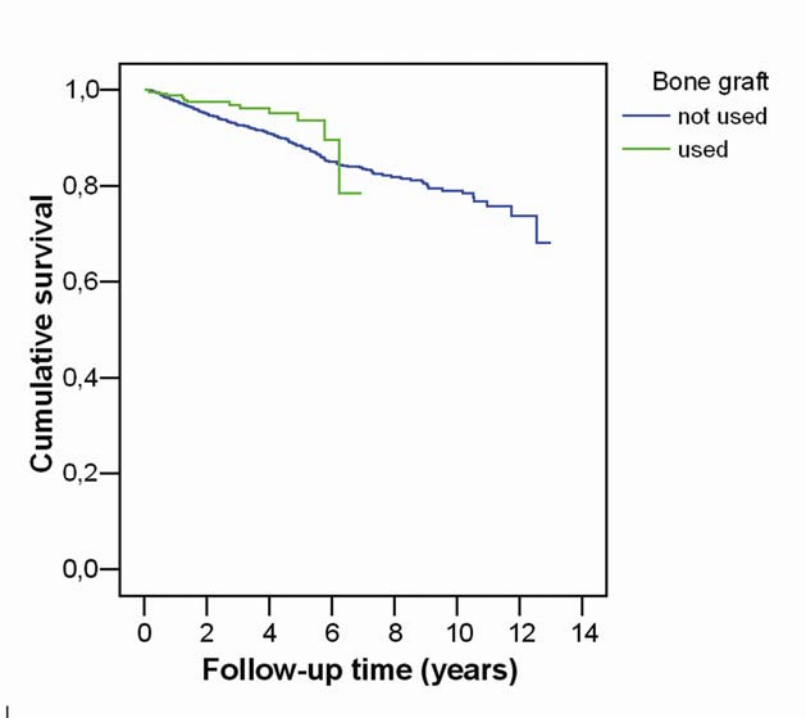

Figure 11. Cumulative survival of revision total knee arthroplasty based on the use of structural bone allografts, which were used if considered necessary and available (group "used") or, alternative, not used (group "not used"). Revision of the rTKA was used as the end-point.

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5.2.4 Multivariate Cox regression analysis

Significant variables were included in the multivariate Cox analysis. Only the age group was significant ($p < 0.005$) in the initial multivariate analysis, which included all variables found to be significant in the univariate analyses—i.e. age group, year of the first revision operation, time between the primary and revision operations, reason for revision, brand of prosthesis, fixation, use of bone grafts, and gender. However, 57% (1514) of the 2,637 knees were missing from the analysis, mainly because of missing information regarding the brand of prosthesis and the fixation method. While our statistical software package can include cases with missing values, this was not considered appropriate (Pelz and Klein, 1996) and a subanalysis was done without those variables (that is, after omission of the brand of prosthesis and fixation method). In this analysis, an age of more than seventy years, having the first operation after 1996, five years or more of service of the primary prosthesis prior to the revision, and absence of patellar subluxation were all found to be significantly associated with improved survival of the revision.

5.2.5 Model diagnostics

We found no extreme values or outlier observations that would have dominated the model individually and resulted in a misrepresentative model.

5.3 Revision total knee arthroplasty with the Total Condylar III system (study III-IV)

5.3.1 Clinical results

5.3.1.2 In the osteoarthritis and inflammatory arthritis group

One year after the revision operation and at the final follow-up visit, improvements were observed in the Knee Society knee score, function score, range of motion, pain score, walking score and stair climbing score compared to the preoperative state before the revision ($p < 0.001$ for all, t-test) (Table 5). 58/71 (0.8) cases had an excellent or good outcome (44 excellent and 14 good). 3 cases had a fair outcome and 9 cases a poor outcome (Table 6). No statistically significant differences were observed between inflammatory arthritis and OA, although the results obtained in inflammatory arthritis showed a slight trend towards a better outcome (Tables 6 and 7).

Table 5. The clinical and radiological status of all TC III operated patients before the operation and at one year after revision and the final follow up visit.

	Pre-operatively	One year Follow-up		Final follow-up	
	Mean ± SD		P	Mean ± SD	P
Knee score	44 (19)	89 (13)	< .0001	84 (16)	**< .0001**
Function score	30 (24)	53 (27)	< .0001	44 (31)	**< .0001**
Range of motion °	78 (42)	102 (21)	< .0001	100 (26)	**< .0001**
Pain score	24 (13)	46 (9)	< .0001	42 (13)	**< .0001**
Walking score	19 (8)	29 (8)	< .0001	27 (11)	**< .0001**
Stair climbing score	19 (15)	32 (13)	< .0001	29 (16)	**< .0001**
Tibio-femoral angle °	2 (5)	6 (3)	.004	6 (3)	**< .0001**
Femoral angle °	96 (3)	97 (2)	.7	96 (2)	.8
Tibial angle °	87 (5)	89 (2)	.008	89 (2)	**.001**
Femoral stem-femur angle °	5 (7)	3 (2)	.02	3 (2)	**.03**
Tibial tray, posterior slope °	5 (7)	2 (3)	.005	2 (2)	**.001**
Tibial tray, anterior tilt °	3 (5)	1 (2)	.007	1 (2)	**< .0001**
Tibial tray shift (AP) mm	1.8 (1.9)	1.2 (1.5)	.1	1.2 (1.6)	.06
Tibial tray shift (lateral) mm	1.2 (2.1)	1.1 (1.4)	.7	0.8 (1.1)	.2

Table 6. Overall clinical results of TC III knee revision surgery in osteoarthritis compared to those obtained in inflammatory arthritis. (Based on the Knee Society Clinical Rating System)

Result	Total	Osteoarthritis	Inflammatory arthritis
Excellent	44	33	11
Good	14	11	3
Fair	3	1	2
Poor	9	9	0
Total	70*	54	16
Chi-Square test		P > 0.05	

* Clinical data was missing in one case

Table 7. Comparison of the clinical and radiological outcome after TC III total knee replacement surgery in osteoarthritis (OA) and inflammatory arthritis (IA).

	Osteoarthritis	Inflammatory Arthritis			
	No		X^2	P	
Gender (male/female)	12/43	3/13	0.086	> 0.05	
	Mean(SD)		t-value	P	
Age (y)	72(7)	59(13)	5.414	**0.000**	
Follow-up time (y)	5.8(1.5)	6.1(2.0)	-0.586	0.564	
	One year follow-up			Final follow-up	
	OA	IA	P	OA	IA	P
Knee scores	89(11)	93(6)	0.187	82(17)	88(12)	0.167
Function scores	56(25)	44(31)	0.127	47(31)	34(35)	0.149
Range of motion °	104(16)	97(32)	0.264	100(24)	98(32)	0.805
Pain scores	45(10)	49(2)	0.004	41(14)	44(11)	0.471
Walking scores	29(8)	25(11)	0.181	27(11)	22(12)	0.141
Stair scores	32(14)	24(18)	0.040	29(16)	24(19)	0.293
Tibio-femoral angle °	6(3)	6(2)	0.969	6(3)	6(3)	0.539
Femoral angle °	96(2)	96(2)	0.988	97(2)	97(2)	0.397
Tibial angle °	89(2)	89(2)	0.914	89(2)	89(2)	0.509
Femoral stem-femur angle °	3(3)	3(3)	0.720	3(2)	2(2)	0.174
Tibial tray, posterior slope °	2(3)	0(2)	0.003	2(2)	0(2)	**0.009**
Tibial tray, anterior tilt °	1(2)	1(2)	0.840	1(2)	1(2)	0.565
Tibial tray shift (AP) mm	1.3(1.4)	0.6(1.5)	0.113	1.5(1.9)	0.7(1.3)	**0.044**
Tibial tray shift (lateral) mm	1.0(1.4)	1.1(1.4)	0.830	0.9(1.2)	1.3(1.4)	0.228

One patient with OA in whom a structural allograft was used to repair a major bone defect had a knee score of only 28 points at the end of her 5.5 year follow-up. She had had a bilateral knee arthroplasty, the other side being a primary TKA. She had moderate but continuous pain, 15° extension contracture and 3-5° valgus, but the knee was stable, there was no resorption of the bone allograft and no radiolucencies around the implant components.

Before revision TKA, remarkable angular deformity (> 11° valgus or varus) was observed in 9 knees and a milder deformity in 31 knees. The tibio-femoral angle was neutral in 32 knees. Severe anterior-posterior instability was observed in 12 knees and severe medio-lateral instability in 21 knees. 12 knees were stable in both directions. Tibio-femoral angle and stability were restored in all knees except in one patient, who had severe but stable valgus deformity observed at the 5 year follow-up.

5.3.1.2 In the inflammatory arthritis group

Average Knee Society knee scores improved from the preoperative 37 (range 0–77) to a postoperative 88 (range 61–100) at the final follow-up ($P < 0.001$, t-test). The mean Knee Society score for pain improved from 22 (range 10-45) to 44 (range 20-50; $P < 0.05$, Wilcoxon's test). Before surgery, 12 knees (75%) had moderate or severe pain on weight-bearing, but at the end of the follow-up only 2 knees had moderate or severe pain and there was no pain in 10 (63%) of the knees. The mean range of motion was 6-68° of flexion and improved to 66-98° indicating a statistically significant improvement ($P < 0.05$, Wilcoxon's test). Severe antero-posterior instability (> 10 mm) was observed in one and mild or moderate (5 - 10 mm) in four knees.

Severe medio-lateral instability (> 15°) was observed in three knees and mild or moderate (6-14°) in nine knees, whereas three knees were stable in both directions. Remarkable angular deformity (varus or > 11° valgus) was present in one knee and mild valgus (0-4°) in three knees. Postoperatively, stability and the tibio-femoral angle had improved in all knees with no severe and only two mild medio-lateral instabilities at the follow-up.

The average Knee Society function score did not improve significantly [26 (range 0-70) vs. 34 (range 0-90); $P > 0.05$, t-test) though the improvement in the walking distance was significant, from 62 (range 0-120) to 98 (range 0-145) points at the end of the follow-up ($P < 0.05$, t-test). The stair climbing score did not change [17 (range 0-50) vs. 21 (range 0-50); $P > 0.05$, t-test].

5.3.1.3 In the group in which a structural bone allograft had been used

The average Knee Society knee scores improved from the preoperative 39 (range 4–51) to a postoperative 81 (range 28-102) at the final follow-up ($P < 0.05$, t-test). The mean Knee Society score for pain improved from 18 (range 0-30) to 42 (range 10-50; $P < 0.05$, Wilcoxon's test). Before surgery, 8 knees (80%) had moderate or severe pain on weight-bearing, but at the end of the follow-up only one knee had moderate pain. There was no pain in 7 (70%) of the knees. 8 (80%) patients retained excellent (6 cases) or good (2 cases) results at the end of follow-up, whereas one patient had a fair and one a poor result. The mean range of motion was 91° (80°-100°) of flexion, which changed to 103° (75° - 125°), which was not significant ($P > 0.05$, Wilcoxon's test).

Severe antero-posterior instability (> 10 mm) was observed in one and mild or moderate (5-10 mm) in four knees. Severe medio-lateral instability (> 15°) was observed in five knees and mild or moderate (6-14°) in four knees, whereas one knee was stable in both directions. Remarkable angular deformity (varus or > 11° valgus) was present in five knees. Postoperatively, stability and the tibio-femoral angle were improved in all knees with no severe and only three mild medio-lateral instabilities at

the follow-up.

The average Knee Society function score (38, range 0-60, vs. 47, range 0-90, t-test), walking distance (20, range 0-30, vs. 24, range 0-40, Wilcoxon's test) and stair climbing score (25, range 0-50, vs. 27, range 0-50, Wilcoxon's test) did not change significantly ($P > 0.05$).

5.3.2 Radiological results

5.3.2.1 In the osteoarthritis and inflammatory arthritis group

The tibiofemoral angle 6^{o} ($p = 0.004$) and posterior slope of the tibial tray 2° ($p = 0.005$) improved from the preoperative state to the end of the follow-up. In the lateral view, the femoral component was in 5° (SD 7 of flexion preoperatively and in 3° (SD 2) of flexion postoperatively with respect to the femur ($p = 0.02$, t-test) (Table 5). Except for the posterior slope of the tibial tray and the distance from the centre of the tibial component to the centre of the tibia in the anteroposterior view, there were no differences between inflammatory arthritis and OA (Table 7).

At the tibial or femoral bone-to-cement interfaces, radiolucent lines were seen in 23 of 71 knees (0.3) at the follow-up. 13 knees had radiolucent lines associated with both femoral and tibial components, 9 knees only with the tibial component and 1 knee only with the femoral component. At the femoral bone-to-cement interface, radiolucent lines were mainly seen in zone 1 (four-fifths of all such lines). At the tibial side, the radiolucent lines were seen mainly in zone 1 (two-fifths) and/or 4 (two-fifths of all such lines). The radiolucent lines were thicker than 2 mm (grade III) at the femoral and/or tibial bone-cement interfaces in only 5 cases, and in 3 more cases grade II 1–2 mm radiolucent lines were seen at the tibial bone-cement interface. Otherwise, all radiolucent lines were < 1 mm and represented grade I. Interestingly, none of the patients with inflammatory arthritides had grade II or III radiolucent lines. All 10 patients in whom allograft bone was used had excellent results, with no evidence of resorption, migration or loosening of the components.

Two patient cases of revision TKAs are shown using a series of x-rays. Figure 12 shows an end stage knee in RA (and secondary OA) with major bone defects. A structural bone allograft was used in the primary TKA (Figure 13). After several years this failed, as the structural allograft was to a large extent resorbed (Figure 14). Revision TKA was performed using the specially designed, long-stemmed TC III system (Figure 15). Good alignment and stability were achieved and, therefore, the revision TC III was still in place six years later (Figure 16). A similar sequence is shown for a patient suffering from primary OA in Figures 17-21.

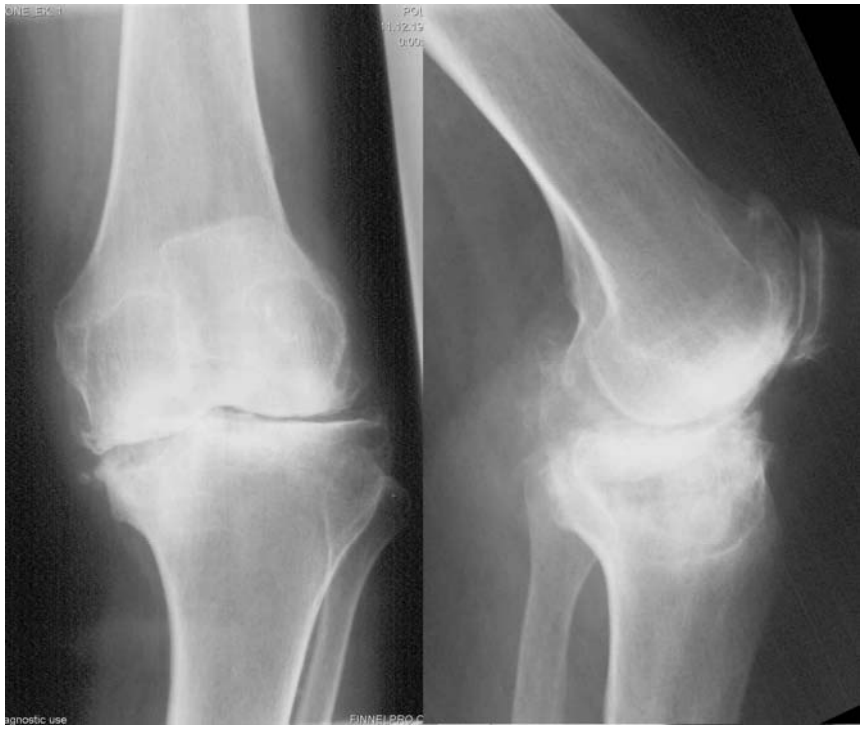

Figure 12. Rheumatoid arthritis and secondary osteoarthritis in the knee of a 77-year-old woman, the antero-posterior view to the left and lateral view to the right. The radiological changes have already reached Larsen's grade IV. The bone heads contain extensive erosions and bone cysts, the joint space (articular cartilage) has been lost and the joint margins are surrounded by extensive osteophytes.

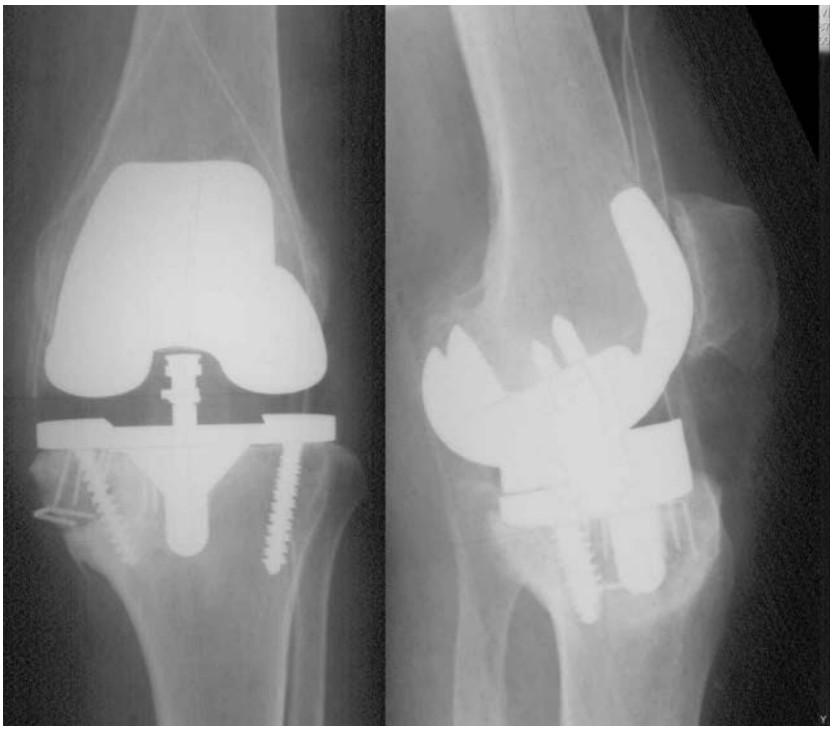

Figure 13. A radiograph taken immediately after the primary total knee arthroplasty reveals structural allografts used to fill the extensive bone defects, fixed with pins. The patella was not resurfaced.

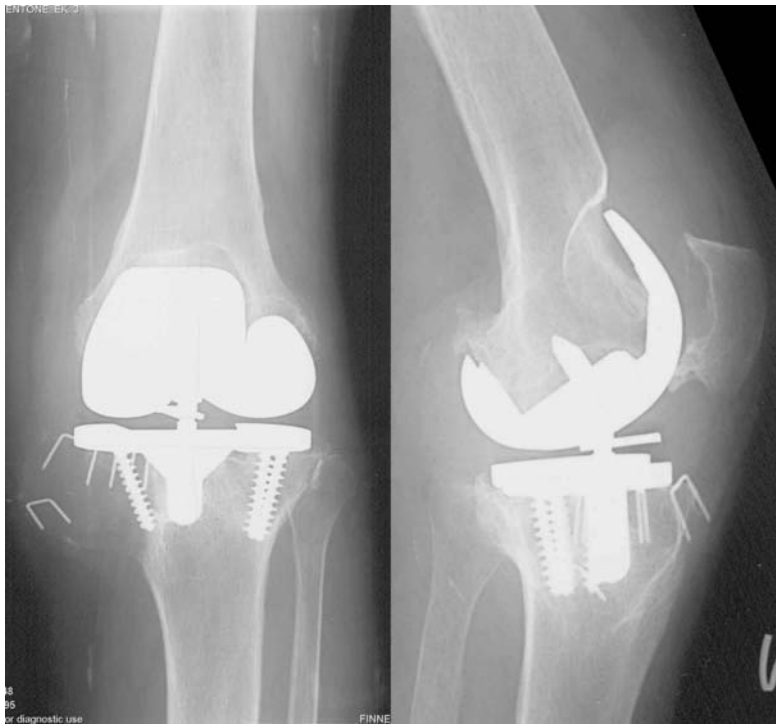

Figure 14. A radiograph taken 10 years after the primary total knee arthroplasty reveals loosening of the femoral and tibial components. The pins used to hold the allograft in place have come loose and migrated from their original positions into surrounding tissues at the same time as the large-size structural allograft on the tibial side has largely been resorbed.

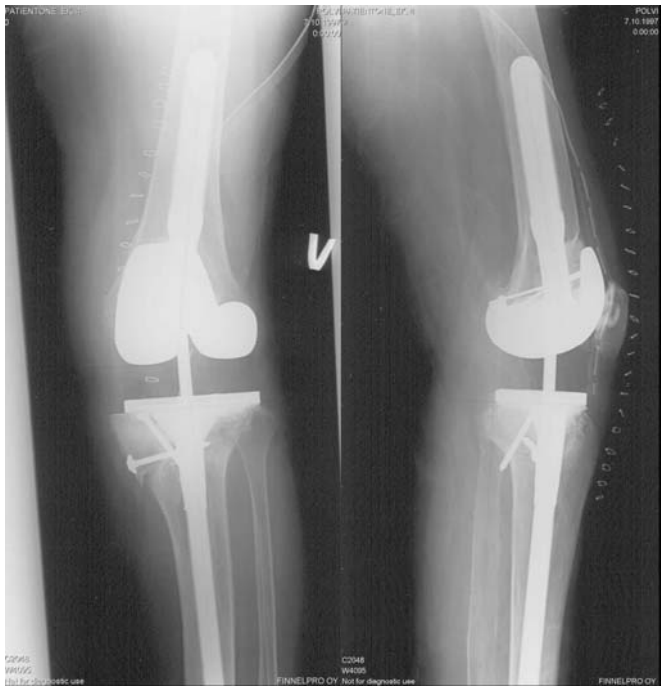

Figure 15. Due to the failure of the primary total knee arthroplasty, a secondary revision operation (revision total knee arthroplasty) was performed using the specially designed constrained revision prosthesis, the TC III system, the fixation of which was ascertained using structural allografts fixed with screws. Note that the stem of the femoral and tibial component is long to facilitate fixation.

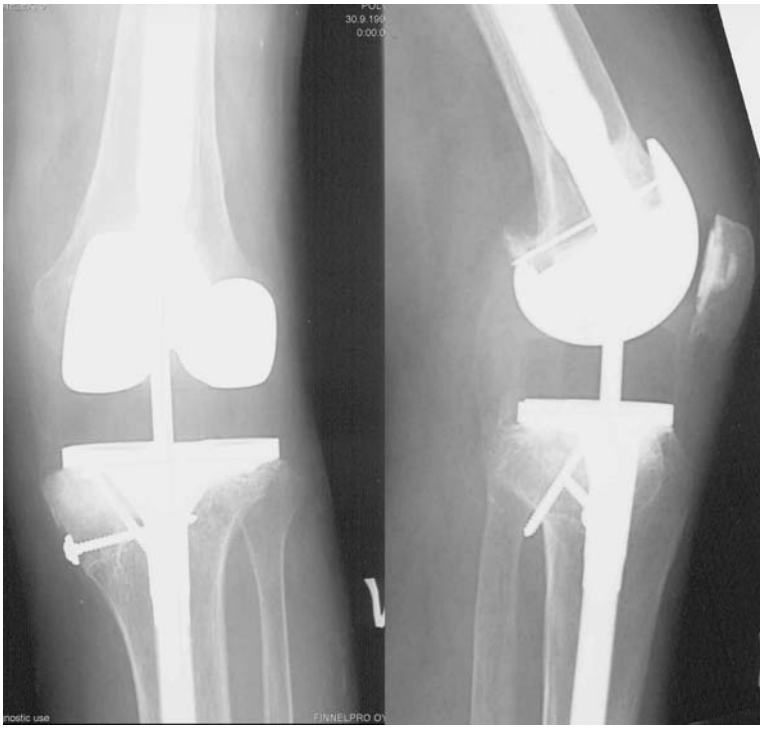

Figure 16. Follow-up antero-posterior and lateral radiographs taken 6 years after the revision total knee arthroplasty show no evidence of loosening. There are no radiolucent lines at the bone-cement interface around either of the components, and no evidence of resorption of the structural allografts, which were used to facilitate fixation of the TC III revision implants.

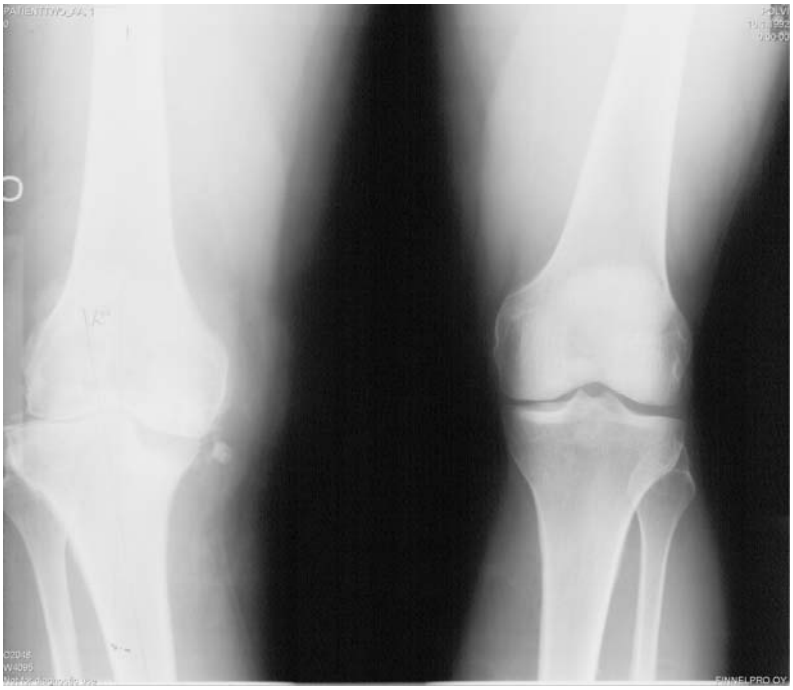

Figure 17. An 83-year-old women with severe osteoarthritis of the right knee in the antero-posterior view. Notice the much better preserved left knee, which has quite a wide joint space compared to the much narrower or almost totally lost joint space on the right side. These preoperative radiographs also show varus deformity and advanced destruction of the bone of the medial tibial condyle in the right knee.

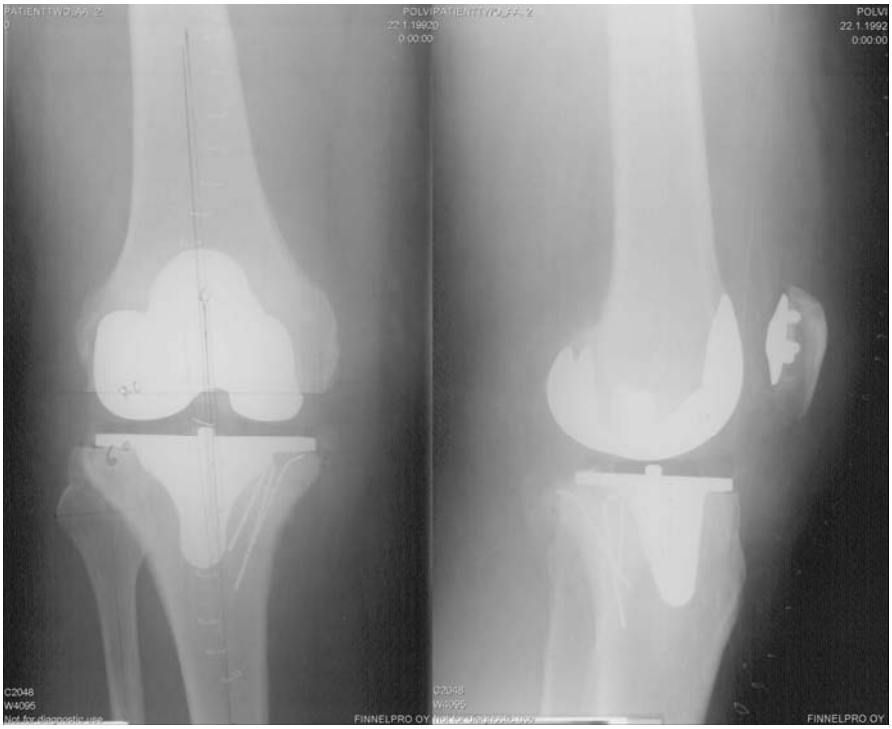

Figure 18. Anterior-posterior and lateral radiographs taken immediately after the primary total knee arthroplasty showing femoral, tibial and patellar components in place. The destroyed medial tibial condyle was reconstructed and the axis of the knee was re-established using a structural bone allograft, which was fixed using pins.

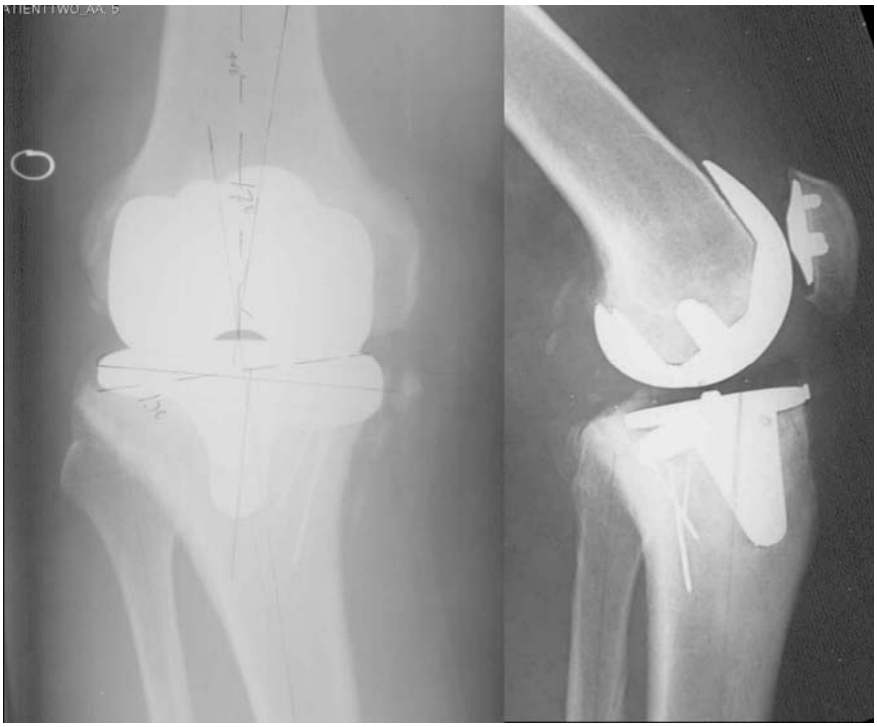

Figure 19. Antero-posterior and lateral radiographs taken four years after the primary total knee arthroplasty reveal loosening of the tibial component. The tibial tray is broken and much of the structural allograft bone has been resorbed.

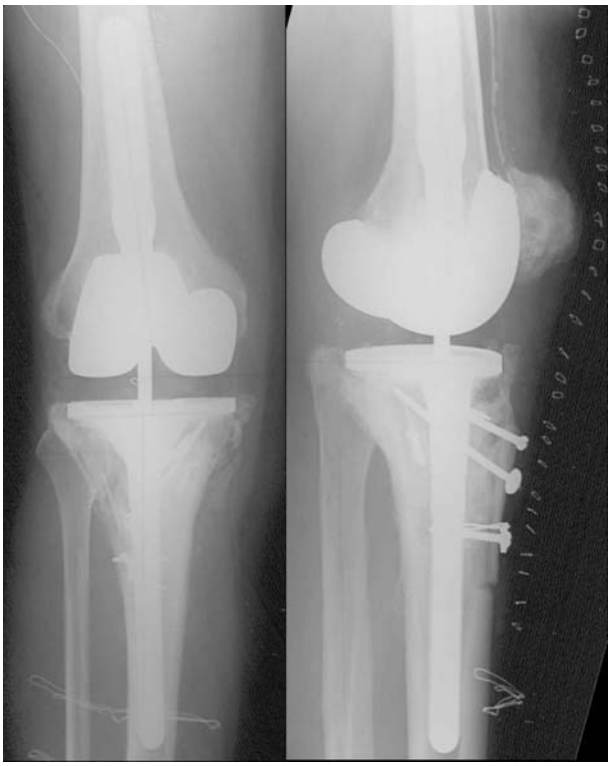

Figure 20. Antero-posterio and lateral radiographs taken immediately after the revision total knee arthroplasty surgery. A revision TC III prosthesis was used, together with a structural bone allograft fixed with screws.

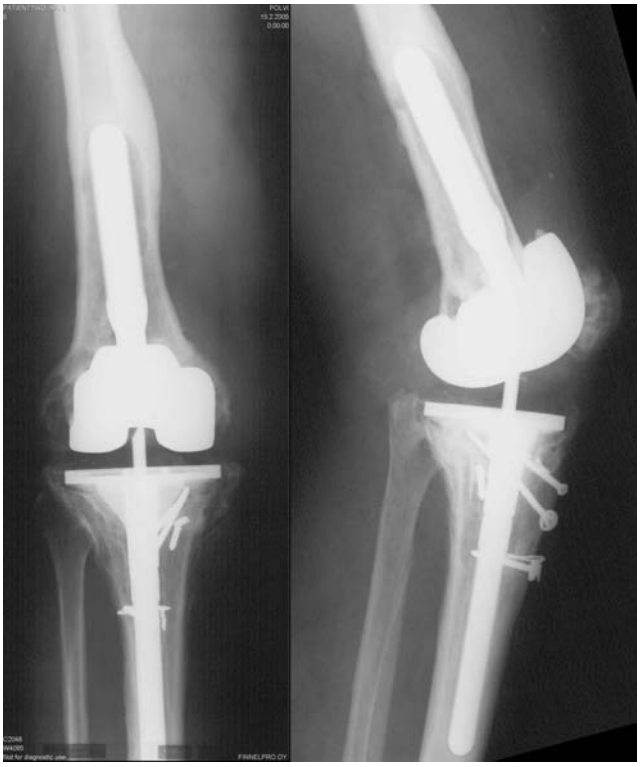

Figure 21. Antero-posterio and lateral radiographs taken six years after revision total knee arthroplasty show no evidence of loosening, no radiolucent lines at the bone-cement interface around the components and no evidence of resorption of the structural bone allograft.

5.3.2.2 In the inflammatory arthritis group

The overall mean femoro-tibial angle changed only slightly from 4 to 6°, the femur angle from 96° to 98° and tibial angle from 88° to 89° from the preoperative state to the end of the follow-up (not significant). The tibial tray improved from 1.8° of valgus (range from 5.9° varus to 8.1° valgus) preoperatively to 0.9° of varus (range from 2.8° varus to 6.6° valgus) postoperatively and the posterior slope from 6.2° (range from -7.6° to 29.0°) to 0.6° (range from -2.7° to 2.7°; $P < 0.05$, t-test). In the lateral view the mean flexion of the femoral component changed from 6° flexion (range from 10° extension to 30° flexion) preoperatively to 2° flexion (range from 3° extension to 5° flexion) postoperatively. The mean distance from the centre of the tibial component to the centre of tibia changed from 1.7 mm preoperatively to 0.6 mm postoperatively in the antero-posterior view of the knee and from 2 mm to 1.6 mm in the lateral view.

At the tibial or femoral bone–cement interfaces, radiolucent lines were seen in 5 of 16 knees (31%) after the follow-up for more than 7 years. 4 knees (25%) had radiolucent lines associated with both the femoral and tibial components and one knee (6%) only with the tibial component. At the femoral bone–cement interface, radiolucent lines were mainly seen in zone 1. At the tibial side radiolucent lines were mainly seen in zone 1 and/or 4. All radiolucent lines were < 1 mm and none of the knees had a radiolucent line > 1 mm thick at the femoral or tibial bone–cement interfaces.

5.3.2.3 In the group using the structural allograft

The overall mean femorotibial angle changed from 1° to 5° ($P < 0.05$, Wilcoxon's test), femur angle from 94° to 96° ($P > 0.05$, t-test) and the tibial angle from 85° to 89° ($P < 0.05$, t-test) from the preoperative state to the end of the follow-up. Tibial tray improved from 4.7° of valgus (range from 4.0° varus to 12.0° valgus) preoperatively to 1.0° of varus (range from 1.2° varus to 3.2° valgus) postoperatively ($P < 0.05$, t-test) and the posterior slope from 9.8° (range from -3.1° to 29.0°) to 2.4° (range from -1.1° to 5.9°; $P > 0.05$, Wilcoxon's test). In the lateral view the femoral component changed from a mean 7° flexion (range from 10° extension to 7° flexion) preoperatively to 3° flexion (range from 1° flexion to 6° flexion, $P > 0.05$, Wilcoxon's test) postoperatively. The mean distance from the centre of the tibial component to the centre of the tibia improved from 0.8 mm preoperatively to 0.7 mm postoperatively in the antero-posterior view of the knee and from 2.0 mm to 1.5 mm in the lateral view ($P > 0.05$, Wilcoxon's test).

At the tibial or femoral bone–cement interfaces, radiolucent lines were seen in 2 of 10 knees (20%) after the follow-up ofor more than 4 years, and all occurred in the tibial component. All radiolucent lines were < 1 mm and none of the knees had a radiolucent line > 1 mm at the cement interfaces.

5.3.3 Complications

By the end of August 2003 three of the 71 Total Condylar III implants were removed, all due to infections. In the female patient suffering from juvenile chronic arthritis, the patellar component loosened and had to be removed six months after the index surgery, followed by the removal of the whole infected prosthesis one year and ten months later. Another infected prosthesis was removed 4.75 years after revision TKA. This female patient had a history of a previous infected knee replacement that was originally performed for OA. In both of these two cases, a hinge prosthesis was later implanted in the second stage of the two-stage revision procedure. The third infectious failure occurred 5.4 years after the primary revision operation. This patient suffered from diabetes, neuropathy and chronic ulceration of the lower limb and was treated with thigh amputation. His primary total knee replacement was performed for OA and he had also undergone one earlier revision operation.

Other complications which, however, did not require removal of the prosthesis or any of its components, were found in three patients suffering from inflammatory arthritis. The first was a staphylococcal infection of the endoprosthesis treated successfully with long-lasting antibiotic therapy. In this patient, the patellar component came loose and a fistula developed, which later became infected. The second patient had had a structural allograft to repair a major bone defect, but later developed severe patellar pain, which was successfully treated with resurfacing one year after the revision. The third patient had a patellar fracture at 3.75 years and reconstruction of the patella and patellar tendon was tried twice, the second time using hamstring tendon. These attempts failed and active extension remains impossible.

Therefore, postoperative complications occurred in 6 knees (8%), of which 3 (19%) represented the inflammatory arthritis group and one (10%) the structural allograft group.

5.3.4 Survival analysis

After it had been ensured from the Finnish Arthroplasty Register that none of the patients, except for the three mentioned above, had had re-revisions in any other hospitals, the situation as of 31 August 2003 was used in the survival analysis. Using any re-revision of the prosthesis as the end-point, the 5-year survival was 95% and the 8-year survival 94 %. Using removal of the prosthesis as the end-point of follow-up, the 5-year survival was 96.7% (CI 91.8-101.3%) and the 8-year survival 93.8% (CI 86.7-100.9%). The patient numbers available for analysis were 43, 20, 9 and 3 at 5, 6, 7 and 8 years. With any failure as the end-point, the 5-year survival was 93.2% (CI 86.7-99.7%) and the 8-year survival 90.5% (CI 82.3-98.7%). The patient numbers available for analysis were 42, 19, 9, and 3 at 5, 6, 7 and 8 years (Figure 22).

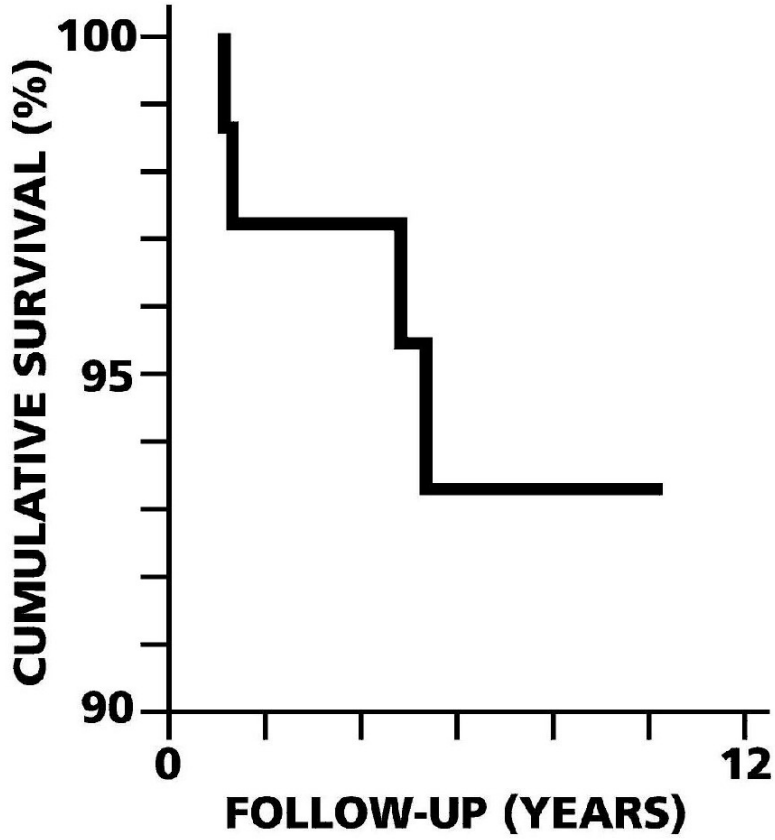

Figure 22. Kaplan Meier survival curve of the cumulative survival of the TC III arthroplasty implants over time, using any re-revision as the end-point.

6. DISCUSSION

6.1 Patient outcome following revision total knee arthroplasty (study I)

This study summarizes the results of a systematic review of literature reporting on patient outcomes following revision total knee arthroplasty. The goals of this analysis were to provide estimates of the expected patient outcomes and to identify clinically relevant questions concerning revision total knee arthroplasties that are not readily answered by a literature analysis of the already existing bulk of data. This type of approach is particularly useful when the literature concerning the intervention in question comprises numerous small studies that perhaps report conflicting results (L'Abbe et al, 1987; Thacker, 1988), as was to some extent the case regarding revision TKA.

The mean knee scores improved from 52 to 92 points as a result of the operation. The mean range of motion of the revision-operated knees improved similarly from 85° to 97° and the knee function scores from 29 points to 54 points. These improvements in the Knee scores, Range of Motion and Function scores were statistically significant. A time-dependent trend was also noticed, in that the results of the operations and, thus, the postoperative global knee scores tended to be higher in the more recent reports than in those published previously (Bradley, 2000; Barrack et al. 2000b, Barrack et al. 2000c). This temporal trend may represent the outcome of improvements in prosthetic design, surgical and cementation techniques, patient selection or postoperative management. Clearly, knee revision seems to be an effective procedure in the majority of patients reported in the literature. This, however, might also to some extent be due to a selection bias, as literature reports on these types of operations are usually produced in the leading clinical centres in the field. It might be that smaller centres or centres with much less experience of these operations are neither able nor willing to report their results or failures, and this might skew the data. This is later dealt with as the results extracted from the nationwide Finnish Arthroplasty Register are presented.

As for the type of prostheses used for revision TKA, it was found that the surgeons seemed to prefer posterior cruciate ligament sacrificing but posterior cruciate ligament substituting prosthesis and posterior cruciate ligament sparing prosthesis for revision total knee arthroplasty, whereas physically linked and constrained hinge protheses were relatively rarely used. However, due to relatively low numbers and much lacking data leading to exclusions, it was not possible to compare different types of prosthesis against each other for superiority. Therefore, it is not possible at present to give general recommendations for the selection of the type and design of implant preferable for revision total knee arthroplasty.

For the future development of new prosthesis brands, it would be useful to know why the designs in current use fail. A systematic literature analysis disclosed that aseptic loosening is the most common cause for the loosening of primary total knee arthroplasty implants and is thus the most common indication for the revision total knee arthroplasty operation. The loosening rate the revision-operated patients in these studies was 55%. Interestingly, some other reasons often indicated as the reason for

revision TKA were polyethylene wear (11%), instability (10%) and osteolysis (4%). As there may be several reasons for the revision operation, these changes might not necessarily be independent. It is plausible that cyclic mechanical loading of the weight-bearing artificial knee (which is not able to regenerate) leads to polyethylene wear, which simulates osteoclast formation ("particle disease") and peri-implant bone loss leading or at least contributing to instability. If this line of reasoning holds, it would mean that attention should be paid to implantation into the correct alignment to minimize mechanical stresses, and also to the development and use of wear-resistant gliding pairs. Infection was given as the reason for revision in 7% of the cases, which seems to be a somewhat higher figure that is seen nowadays. This improvement might result from preoperative sanitation of infectious foci, the prophylactic perioperative use of antibiotics, fixation with antibiotic-containing cement and careful post-operative monitoring for eventual implant infections. On the other hand, as resistant hospital strains of various bacteria such as meticillin-resistant Staphylococcus aureus and new species of resistant bacteria emerge, the rate of implant infections may start to increase again. Progression of the underlying disease and bone fractures were both indicated as the reason for revision in 4% (total 8%) of cases and here, too, the development of modern medicine may help to decrease this figure as more effective drugs and strategies are developed to control inflammatory arthritis <e.g. early treatment, treatment with drug combinations, the saw tooth principle and biological and other new anti-rheumatic drugs (Konttinen et al. 2005)> and metabolic bone diseases <e.g. anti-resorptive bisphosphonates and bone gaining teriparatide (Konttinen et al. 2006)>. Component failure was reported in 3% of cases and may also be declining as a result of new developments in biomaterial sciences and better designs. Stiffness (1%) and pain of unknown origin (1%) were "orphan" causes for revision, which may relate to scar formation, inadequate post-operative rehabilitation and operative failures, such as nerve injuries. On the other hand, the widening of the indication for total joint replacement to both younger and older and more severely ill patients may cancel out these anticipated advances.

The overall effectiveness of revision total knee arthroplasty must be considered in light of the complication rates and the seriousness of these complications. In this literature study, the mean complication rate was relatively high (19%). The most common complications were loosening (18%), instability (16%), infection (16%) and patellar failure (15%). The patellar failure includes patellar subluxation, patellar dislocation, patellar tendon avulsion, patellofemoral pain and clunk. This indicates that revision total knee arthroplasty presents a technical challenge and is associated with higher risks than the primary total knee arthroplasty. The literature analysis as such did not directly provide any clues or statistical data indicating how to improve this situation, but it was interesting in our future studies (see below) to notice that the complication rates were relatively low in a revision TKA series which was performed by a few specialized revision surgeons always using the same and purpose-designed revision total knee prosthesis.

This systemic review of the literature had several limitations. Although such techniques can help provide more precise estimates for the outcome, none of the

filtering or pooling procedures performed in such studies and also in this study can rectify missing data, biases or methodological flaws present in the original studies. Publication bias or the underreporting of studies with negative outcomes could also artificially inflate pooled estimates of the impact of intervention. However, it seems fair to conclude that revision total knee arthroplasty is a safe and effective procedure for patients, though the mean complication rate is high.

6.2 Review of the Finnish Arthroplasty Register for revision total knee arthroplasty (study II)

One of the assumptions of the Cox regression analysis is that the observations are independent from one another. In reality, the two knees of one patient are not independent of each other, and this must be considered when both knees are operated on. It has, however, been reported that the effect of not accounting for bilateral prostheses is minute, and that the risk of the revision of knee prostheses can be analyzed without consideration of dependency (Robertsson and Ranstam, 2003). In the present study, a relatively small proportion (11.3%, 297) of the 2,637 knees were in patients with a bilateral revision, and the survival analyses were carried out without taking bilaterality into account. A subanalysis indicated that bilateral knee revision was associated with better survival than was unilateral knee revision. This finding is in accordance with the finding of better survival of bilateral primary TKA compared to unilateral primary TKA (Rand et al. 2003).

Age group was a significant predictor of prosthetic survival, with an age of greater than seventy years being associated with better survival ($p < 0.005$). The quality of bone declines with age as a result of senile osteoporosis. However, the reduced physical activity of elderly people diminishes cyclic loading and micromotion. A reduced activity level and low body weight may explain why a long interval between the primary and revision operations predicts a long survival of the revision replacement, but this cannot be proven because physical activity and weight are not recorded in the Finnish Arthroplasty Registry. To some extent, the effect of the patient's age may reflect surgeons' reluctance to perform repeat revisions in elderly and frail patients. Age in itself cannot be considered as a contraindication for revision knee arthroplasty. On the contrary, it seems that revision knee prostheses can be expected to have a long service life in elderly patients.

The outcomes of primary arthroplasties have been relatively good in patients with RA, although this disease is characterized by destruction of cartilage and bone, ligamentous laxity, and juxta-articular and generalized osteoporosis (Peters et al, 2001; Ranawat et al, 1984; Rand et al. 2003; Stern et al, 1991; Strand and Kavanaugh, 2004; Westhovens and Dequeker, 2000). It is interesting that in the Finnish National Arthroplasty Register, only 1.1% of arthritides are other than RA or OA, which may indicate that reporting of the type of inflammatory arthritis by the orthopaedic surgeon is perhaps not very accurate. The differences in prosthetic survival between knees with a diagnosis of OA and those with RA, and between men and women, were significant in the study of primary knee replacements ($p < 0.001$ and < 0.0001,

respectively) (Rand et al. 2003). This was not the case in our study of revision knee replacements. This difference may be due to the fact that patients who had already been treated with primary knee arthroplasty had adapted to a reduced activity level so that any pre-existing differences were diminished.

The type of hospital where the patient had undergone revision arthroplasty (i.e. a university or central, regional or other type of hospital) was not a significant predictor of prosthetic survival in our analyses. However, it should be noted that during the follow-up period, specialization in the different fields of orthopaedics very often had not yet developed, even in large units, in Finland (Nevalainen et al. 2000). Therefore, some orthopaedic surgeons performed only a few arthroplasties in a year. On the other hand, large hospitals that had achieved a good reputation in a certain field may have attracted more patients with more difficult cases, and this may have worsened the results in those hospitals. Concurrently, the high number of revision operations needed and the long waiting times sometimes led to a revision being performed only when it could no longer be avoided (Nevalainen et al. 2000). This may have improved the prosthetic survival figures for individual units. However, the registry provides the nationwide mean for the outcome of revision total knee arthroplasty in Finland, which can be considered to be one of its major advantages.

Patellar subluxation seems to adversely affect the outcome of revision knee replacement, indicating that surgeon-related factors are in part responsible for the failure of some of these procedures. In the Finnish Arthroplasty Register, the types of patellar complications are not specified so the role of e.g. patellar pain syndromes as a reason for revision cannot be evaluated. This finding is consistent with those of our study III-IV, which demonstrated an excellent or good result in 82% (fifty-eight) of seventy-one patients, a high (94%) eight-year survival rate combined with a low (8.5%) complication rate (six of seventy-one), and very few and asymptomatic radiolucent lines around TC III revision total knee prostheses (Johnson and Johnson, Braintree, Massachusetts) when these operations were performed by a few experienced revision surgeons. Furthermore, only 5% (115) of the 2,443 revisions in the present study for which the reason for revision was known resulted from infection. This might to some extent represent underreporting, but this seems unlikely considering the wide coverage of the registry, which was estimated to be 90% to 95% even in the early 1990s when registration was still voluntary (Nevalainen et al. 1997).

To improve feedback and quality control, the Finnish Arthroplasty Registry is being further developed so that it will, perhaps in the near future, be possible for individual surgeons to confidentially check their personal performance online in relation to the nationwide norm. The surgeon is responsible for the selection of the brand of prosthesis, the fixation method and the use of bone grafts, which may affect the survival of revision total knee replacements. Many different brands have been used in Finland, and only the most commonly implanted were included in our analyses. Many of the new brands had been used in a very small number of knees, so more observations are needed before reliable survivorship analyses of those brands in a clinical setting can be performed.

Rand *et al.* found that primary TKA can be expected to have the most durable results in women who are more than seventy years of age, have inflammatory arthritis, and are treated with certain types of prostheses (Rand et al. 2003). They also reported that the cruciate-retaining design was better than the cruciate-sacrificing design in primary TKA. Detailed information about the status of the cruciate ligament was not available in the Finnish Arthroplasty Registry. On the basis of the results of the present study, it can be concluded that revision TKA can be expected to have the most durable results in patients who are older than seventy years of age and in whom the primary implant had been in service for a long period of time. Absence of patellar subluxation is also a positive indicator.

Gender and diagnosis did not predict the survival of the revised TKA, perhaps because the patients had adapted to a reduced activity level after the primary TKA. Recent advances in implant materials, designs, and operative and fixation techniques presumably have improved implant survival. Indeed, the results of revision TKA in Finland have improved since the early 1990s.

The arthroplasty register, despite many advantages such as large patient numbers and the provision of data from the whole health care system, also has its disadvantages. Comparisons with the Hospital Discharge Register and other registers suggest that the recording of the data is not quite correct and covering. Secondly, more detailed information, like radiological loosening, the functional status of the patient and the sacrifice of the cruciate ligaments, etc., are not included at all. Therefore, a more detailed analysis of clinical cohorts should be carried out to obtain more reliable and valuable information. In this particular study, such information was sought from some patients undergoing revision TKA using a special revision prosthesis.

6.3 Revision total knee arthroplasty with the Total Condylar III system (study III-IV)

Many reports have combined the results of complex primary and revision total knee arthroplasties using the TC III system (Rand, 1991; Kim, 1987; Donaldson et al, 1988; Bush-Joseph et al, 1989; Rosenberg et al, 1991). Donaldson et al. reported 14 revisions with 50% excellent or good results and 18% complication rate at 2.5-8 year follow-ups (Donaldson et al, 1988). Bush et al. described revision total knee arthroplasty using the TC III System in 33 knees with 44% excellent and good results and a 38% complication rate at the 4-year follow-up (Bush-Joseph et al, 1989). A summary of these and other earlier reports is shown in Table 8.

Compared with these earlier studies, ours is the largest when both the number of knees and length of the follow-up are considered. The most striking finding was that in this large study, excellent outcomes were so often reached in revision total knee arthroplasties with the TC III system. When similar criteria for outcome were used, excellent or good results were obtained in 82%, whereas the complication rate was only 8.5%. However, these other studies are very old, from the years 1987, 1988, 1989, 1991 and 1991. Since then, the design of prostheses has changed, bone transplantation has been taken into relatively widespread use and cementation

Table 8. Results of TC III in revision total knee arthroplasty according to literature analysis.

	Number of knees	Excellent or good	Complication rate	Follow-up time
Kim *et al.* 1987	14	-	14%	4.2 years
Donaldson *et a.* 1988	14	50%	18%	2.5-8 years
Bush *et al.* 1989	33	44%	38%	4 years
Rand *et al.* 1991	21	50%	33%	4 years
Rosenberg *et al.* 1991	36	69%	33%	3.75 years
This study	71	82%	8.5%	5.9 years

techniques have changed. Although focusing these operations to specialized hospitals and to specialized revision surgeons might partially explain these changes, it is not possible to draw any firm conclusions as to this point, as there are so many possible background factors for these differences.

Many factors which influence the quality of life and activities in everyday living improved, including diminished pain and improved walking ability, stair climbing and range of motion. The maximum range of flexion improved from 78° beyond the critical 100°, which allows one to rise from a sitting position unaided. In our unit, it was decided very early on that these demanding operations will be performed by only two surgeons. Thisa policy was quite successfully realized as it was in retrospect shown that the consequent use of one TKA implant design/modular system, together with the focusing of these operations to only a few highly specialized revision surgeons, has led to a quite excellent or good outcome. Furthermore, the instruments and instrumentation of the TC III system are very similar (although more versatile) to those used in regular primary total knee replacement surgery, which improves the learning curve for those becoming responsible for revision total knee arthroplasties.

In addition to the high proportion of excellent and good clinical results, also the 5-year and longer-term survival rates were high when any re-revision or removal of the prosthesis were used as end-points. It should be emphasized that no patients were lost for control as the results were checked using the nationwide implant register. These are excellent results in revision total knee arthroplasty surgery. As a matter of fact, probably as a result of such good to excellent clinical results, some of the patients were lost from the clinical follow-up but could still be followed by revision surgery using the nationwide Finnish Arthroplasty Register. These high survival rates are probably due to one main reason. The learning curve referred to above apparently enabled restoration of the alignment as measured by any of the parameters applied in the present study, including the femoro-tibial angle, the angle between the femoral component and femur in the lateral view, the posterior slope and anterior tilt of the tibial tray, and the position of the tibial component. This excellent alignment relieves stresses at the cement-to-bone interface. Earlier literature suggests that radiolucent lines occur more often after revision total knee arthroplasty than after primary cases (Insall and Dethmers, 1982; Jacobs et al,1988). Kim identified such lines in 71% of cases around tibial components and in 29% around femoral components (Kim, 1987),

and Rosenberg reported radiolucent lines in 60% of cases already at 45 months after revision total knee arthroplasty using TC III (Rosenberg et al, 1991). Other reports suggest that radiolucent lines occur in 33-72.7% of cases after revision total knee arthroplasty using other prosthetic designs (Peters et al. 1997; Mow and Wiedel, 1998; Takahashi and Gustilo, 1994). In our study, 23 knees (32.4%) had radiolucent lines, all of them asymptomatic. It is noticeable that all more severe radiolucent lines with thickness exceeding 2 mm occurred in OA, none in RA. This may indicate that patients with RA do not or are not able to subject their joints to as heavy use as those with OA. This might contribute to similar results in these two forms of arthritis despite the initial local joint and general health status being worse in inflammatory arthritis than in "degenerative" OA.

The potential factor, which in addition to this good alignment and diminished interface stress may contribute to high survival rates in the present series, is the cementing technique. Although there is no evidence to confirm that the use of this technique contributes to the excellent or good result, we speculate that the third-generation cementing technique contributes to good implant fixation and long-term results. In the third-generation cementing technique, the open medullary canals and metaphyseal cavities are thoroughly washed with pulsed lavage and the bony bed is dried before cementing. The cement is vacuum mixed and centrifuged and a cement gun with a narrow syringe is used. Medullary plugs are used to allow adequate pressurization of the cement before introducing the components in their place. This diminishes crack formation and improves the cement-to-bone contact.

Inflammatory arthritis is often associated with cartilage and bone destruction and ligamentous laxity, incompetence and rupture (Laskin, 1990; Nafei et al, 1996; Kristensen et al,1992; Gill and Joshi, 2001; Gill et al, 1997). In addition, the bone stock is impaired by the local juxta-articular and generalized osteoporotic changes caused by the disease itself and by its treatment with corticosteroids (Peters et al, 1997; Kim, 1987). A non-linked, semi-constrained TC III system provided with an enlarged tibial spine in conjunction with a deep femoral well is specially designed to restore joint stability and to prevent pathological movement of the prosthetized joint. The TC III design apparently puts arthritis patients in this respect to the same line as those suffering from OA. Cement fixation of non-modular stems and correct alignment in the host bone bed in arthritis patients with often only modest physical demands contribute to a long life in service. These features probably explain why the results in inflammatory arthritis were as good as the results in OA. In general, arthritis patients have increased infection rates due to, e.g., immunosuppressive medication, extra-articular complications and local joint damage compared to otherwise healthy patients. Only one out of the four patients with an infection in this series had an underlying inflammatory arthritis, but naturally the size of the present patient population is too small to allow firm conclusions on this point.

For patients with inflammatory arthritis in the present study, revision TKA significantly improved knee pain, range of motion and stability scores. This was accompanied with macroanatomical (radiological) improvements in joint alignment

and some favourable changes in lengthening of the walking distance. Apart from the statistically significant changes to the better, the extent of the improvement and, in particular diminished pain and improved ROM, are of significance to the patients' quality of life and daily activities. This is remarkable because these patients suffer from severe and destructive inflammatory arthritis which had already led to a primary TKA followed by its failure. In the present series, these improvements in the knee and function score were obtained after the revision operation. Apart from register data, clinical studies have shown that anterior knee pain is relatively common in juvenile chronic arthritis if the patella is unreplaced but much more rare if the patella is resurfaced, indicating that some revision TKA operations are done for patellar resurfacing (Lybäck et al. 2004).

The flexion range is an important issue for inflammatory arthritis patients. Getting up from a sitting position usually requires approximately 100° of knee flexion or upper limb support. This is often compromised in inflammatory polyarthritides, like RA. As the inability to get up from a sitting position can be most embarrassing and disturbing in consideration of daily needs, the restoration of an adequate flexion range forms an important goal for TKA. In this study, the mean range of flexion of the knees could be increased from the inadequate 68° preoperatively to 98° of flexion, which was observed also at the end of the follow-up, indicating that this important goal was attained at the revision operation. This functional improvement was accompanied by an improvement in significant instabilities and/or deformities so that, postoperatively, no severe instability and only two mild medio-lateral instabilities were observed at the follow-up, indicating improvements in the relevant range of motion as well as improved stability and alignment.

Apart from the medium-term follow-up, the results in the long-term are affected by the alignment of the knee. In our series, the femoro-tibial angle, tibial angle and angle of the tibial tray improved slightly. Improvements were also evident in the lateral view. This indicates that adequate surgical technique was used. It is apparent that improvements were seen in several measures of importance to the normal biomechanical function of the knee and for the stress distribution in and around the implant and its components. This will greatly affect the cyclic loading and micromotion at the implant-to-host interfaces. The results obtained are almost ideal and suggest that the excellent medium-term follow-up results from the revision TKA using TC III in patients with inflammatory arthritis will probably hold in the long term.

In the inflammatory arthritis group, radiolucent lines occurred almost exclusively in zone 1 and/or 4 and all were < 1 mm in thickness. These results may in part be explained by the experience of the senior revision surgeons, but they are also very promising, indicating that with the proper implantation method, proper load transfer and therefore excellent results can be achieved with the TC III system.

Resurfacing of the patella may be a challenging procedure as inflammatory arthritis reduces patellar bone stock, which is often also weakened by steroids and osteoporosis. There is no clear-cut or universal consensus about the indications for

patellar resurfacing (Stuart et al. 1993, Rosenberg et al. 2003, Rand, 1991, Holt and Dennis, 2003; Boyd et al, 1993). At the time of the primary arthroplasty, resurfacing of the patella was not a rule in our unit if the patella was not distorted and if its bone stock was good, but at the time of the revision operations even a stabile patella button was often replaced. To prevent patellar fracture, cemented extensions were preferred in patients with inflammatory arthritis where the stiffness difference around the tip of the extension against weak cortical bone is relatively high with press-fit extensions.

The results from the inflammatory arthritis series show complications in three cases (19%), which is lower than has been reported in some other series (Rand, 1991; Rosenberg et al, 1991; Stuart et al. 1993;Takahashi and Gustilo, 1994;), but higher than in some other studies (Himanen et al. 2007; Lybäck et al. 2004; Peters et al, 1997; Mow and Wiedel, 1998). One patellar pain syndrome was successfully treated with resurfacing and one deep prosthetic infection with re-revision with a hinged prosthesis, whereas a repair to one patellar fracture failed. Therefore, it can be concluded that these TC III revision knee arthroplasty patients need to be followed and that the complications associated with the use of the TC III endoprosthesis can be usually managed with minor operations or re-revision.

Large bone losses and the associated soft tissue laxity make the revision of the failed knee arthroplasty more challenging and less predictable than primary TKA. The long-term results of TKA are largely dependent on the degree to which the implants and the techniques for their insertion imitate the normal joint anatomy, mechanics, and kinematics (Townley, 1985). In this series of patients with bulk bone defects, the femoro-tibial angle, tibial angle and angle of the tibial tray improved significantly. Improvements were also evident in the lateral view. This indicates that an adequate surgical technique was used. It is apparent that improvements were seen in several measures of importance to the normal biomechanical function of the knee. This probably led to appropriate stress distribution in and around the implant and its components. Therefore, osteolytic lines were few and of minor extent. At the structure-function level this probably contributed to the significant improvement of knee scores and knee pain scores. At the same time, slight improvements were observed in function scores and range of motion. This was accompanied with macroanatomical improvements in joint alignment and some favourable changes in lengthening of the walking distance.

In addition to restored alignment, the selection of revision prosthesis and method of fixation are also very important to the stability of the implants in patients with major bone defects. Fixation was further enhanced by modular stems available win an assortment of diameters and lengths to provide the best fit within the canal of the femur and tibia. This solution, together with the bone allografts, seems to provide support for the implant and helps deter the negative effects of offload forces (Gofton et al. 2002, van Loon et al. 2000) Good osteofixation affects the cyclic loading and micromotion at the implant-to-host and allograft-host interfaces. In our study, the TC III system with optional modular stems, designed primarily to address the issues of bone lose and instability (Donaldson et al, 1988; Kim, 1987), was chosen. Good

results were obtained in this study without non-union or resorption of the structural allograft. Stability was achieved even in the patient who had poor results. One patient had patellar pain, and two had asymptomatic radiolucent lines (< 1 mm) around the implant. These results can perhaps be extrapolated so that the excellent medium-term follow-up results with the revision TKA using TC III in patients with a massive bone defect will also hold in the long term. However, it is impossible to separate the implant and surgeon effect, and it is quite plausible that other implants, too, in the right surgeon's hands, can provide similar results.

The number of patients with inflammatory arthritis and with a major bone defect was relatively small as such patients are rare even in specialized centres, but the study cohort was uniform, none was lost to follow-up and the results are therefore informative. Both clinical and radiological results suggest that TC III is suitable for revision TKA operations at failure of the primary TKA in inflammatory arthritis or with a large bone defect.

In summary, our results demonstrate that in experienced hands, the TC III system performs very well in revision TKA. The non-linked, semi-constrained design allows attainment of good or even excellent clinical results together with high medium-length survival rates if the components are adequately positioned and cemented. The results can apparently be much improved by factors not related to the TC III system itself (which has a good potential), such as the focusing of TC III revision operations to specialized revision surgeons, together with the use of third-generation cementing techniques.

Our results also suggest that revisions of TKA using TC III in patients with OA or inflammatory arthritis and/or with bulk bone defects can have excellent clinical outcomes in the medium term. Although revision TKA with inflammatory arthritis or with bulk bone defects remains a challenging operation, improved surgical methods and prosthesis designs together with modern cementing techniques seem to help obtain results equal to those reported earlier in primary TKA. It may be that the design needs were first met in the primary TKA and that the experience of revision TKA became available afterwards, leading to a later development of special-design revision implants. Despite ligamentous laxity, a propensity for infection, more severe bone destruction and poor general health, patients with inflammatory arthritis had results similar to those in OA.

Currently, computer-assisted surgery (CAS) is creating a new approach to TKA and also to revision surgery to improve component placement and soft tissue balance. Computer-assisted navigation ensures a more predictable result through enhanced precision in positioning and balancing the joint. After an analysis of 18 comparative studies examining the precision of the implantation of knee endoprostheses following CAS and by the conventional technique, Bäthis et al. found that 75.6% (654/865) of TKA were implanted within the safe zone in the group of patients in whom the conventional technique was used, but in the CAS group 93.9% (863/919) was reached ($p < 0.0001$) (Bäthis et al. 2006). Overall, CAS should lead to a better, more predictable outcome and potentially increased mechanical longevity of the implant in

TKA and also in the revision process in the future. At present, the cut necessary to use CAS is larger than that used for conventional surgery, but it can be expected that CAS systems will develop further and in future be more widely used.

Finally, we are cautiously optimistic that the TC III system will continue to show good results also in the longer follow-up as the prognostic factors in terms of alignment and radiolucent lines suggest a good long-term outcome. Hence, the TC III revision knee arthroplasty seems to provide a good option for patients with OA or inflammatory arthritis and/or a bulk bone defect requiring revision TKA.

CONCLUSIONS

Based on the results obtained, the following conclusions were reached.

1. Revision total knee arthroplasty is an effective procedure for arthritis patients, although the mean complication rate at least in the historical series as reported in the literature is relatively high.
2. According to a study using data extracted from the nationwide Finnish Arthroplasty Register, the most durable results in revision total knee arthroplasty can be expected in patients over 70 years of age, who have had a long life in service for their primary total knee arthroplasty, are not subject to patellar luxation or complications, whose prostheses are fixed with cement and augmented with bone grafts. Gender and diagnosis do not predict the survival of revised total knee arthroplasty.
3. Despite ligamentous laxity, a propensity for infection, more severe bone destruction and poor general health, patients with inflammatory arthritis had excellent or good clinical results similar to those of osteoarthritis patients in revision total knee arthroplasty using model revision prostheses.
4. The use of the Total Condylar III system in revision operations, together with the use of third-generation cementing techniques, probably explain the high proportion of excellent or good clinical results together with high medium-length survival rates in patients with inflammatory arthritis.
5. These results suggest that the Total Condylar III system can be used successfully for revision total knee arthroplasty in patients with major bone defects if a structural bone graft is used to repair these defects.

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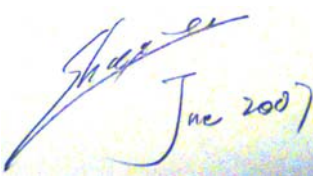

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Revision Total Knee Arthroplasty: 1990 Through 2002

A Review of the Finnish Arthroplasty Registry

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Background: National and regional arthroplasty registries have been used to study the results of primary total knee arthroplasties. The purpose of this paper was to present the results of revision total knee replacements and describe predictors of survival of those replacements, with repeat revision as the end point.

Methods: The nationwide Finnish Arthroplasty Registry included 2637 revision total knee arthroplasties from 1990 through 2002. Survivorship of the revision total knee arthroplasties was analyzed, with repeat revision as the end point. The survivorship analyses comprised evaluations of the proportional hazards assumption followed by calculations of univariate and multivariate statistics and model diagnostics as appropriate.

Results: The survival rate following the revision total knee arthroplasties was 95% (95% confidence interval, 94% to 96%) at two years (1874 knees), 89% (95% confidence interval, 88% to 90%) at five years (944 knees), and 79% (95% confidence interval, 78% to 81%) at ten years (141 knees). Multivariate regression analysis showed the most significant predictors of prosthetic survival to be the age of the patient and the life in service of the primary total knee replacement (that is, the time between the primary total knee replacement and the revision). Survivorship was also significantly predicted by the year of the first revision total knee arthroplasty and the reason for the revision.

Conclusions: An age greater than seventy years, revision five years or more after the primary arthroplasty, and absence of patellar subluxation are positive indicators of survival of a revision total knee replacement. We believe that normal aging as well as the deconditioning effect of disease (osteoarthritis and rheumatoid arthritis) and its treatment (primary total knee replacement) may lead to a reduced activity level, which, together with a presumed reluctance to operate on elderly patients, protects against repeat revisions.

Level of Evidence: Prognostic Level II. See Instructions to Authors for a complete description of levels of evidence.

Despite improvements in joint replacement surgery, the number of revision total knee replacements continues to increase[1]. This has heightened interest in the factors that affect the outcome of revision total knee arthroplasties. National and regional arthroplasty registries have been used to study the results of primary operations[2,3], but to our knowledge no large-scale reports on the results of revision total knee replacements have been published. The Finnish Orthopaedic Association began to register arthroplasty operations in 1980; at present, the registry is run by the National Agency for Medicines. Registration of joint replacements was initially voluntary, but since 1996 it has been statutory, meaning that institutions and orthopaedic units are obliged to provide the National Agency for Medicines with information on a special form. The arthroplasty registry is linked and matched with other national data registries, which allows detection of death of the patient and repeat revision operations in all Finnish hospital districts. In the present study, data from the Finnish Arthroplasty Registry were used to analyze the results of revision total knee arthroplasties performed from 1990 through 2002 and to attempt to determine which factors affect these results.

The goal of this study was to determine the effect of age at the time of the revision operation, gender, diagnosis (rheumatoid arthritis compared with primary or secondary osteoarthritis), year of the first revision operation, time between the previous operation and the revision, reason for the revision, type of prosthesis (hinged compared with condylar), brand of prosthesis, fixation method (cemented, hybrid, or uncemented), use of bone grafts, presence of primary complications, and type of hospital where the operation was performed (university, central, regional, or other) on the outcome of revision total knee arthroplasty, with repeat revision as the end point.

Materials and Methods

Patients

The database maintained by the Finnish Arthroplasty Registry was used as a source for records. Only records on first total knee revisions were included; repeat revisions were excluded.

The Finnish Arthroplasty Registry contained information on 2845 revision total knee replacements performed from 1990 through 2002. Two hundred and eight of those procedures were repeat revisions, which were excluded from the study. The final number of knees analyzed was thus 2637.

The mean age of the patients at the time of revision was sixty-nine years (range, seventeen to ninety-one years). The most common reasons for revision were loosening of the tibial component, the femoral component, or both components (33%) and patellar complications (32%) (see Appendix).

Statistical Analyses

Data were analyzed with SPSS statistical software (version 12.0.1; SPSS, Chicago, Illinois). The factors included in the statistical analyses are presented in the Appendix. Variable descriptives were checked to find any extreme values or errors in data input. Categorical variables were dummy-coded. For the survival analyses, the original data file from the National Implant Registry was organized so that each row represented one knee. The steps in the analysis included checking the adequacy of the proportional hazards (the probability of an end event) assumption[4] by graphical examination of the partial residuals and, more formally, by testing the significance of time dependency (a trend in the partial residuals with time and significance of the time-dependent covariate [that is, an interaction term between the covariate and time] were taken as evidence against the assumption), testing for significant differences in survival with use of Kaplan-Meier survivorship analysis and log-rank tests, calculating univariate statistics for each variable, entering significant variables into a multivariate Cox model, and using Cox regression model diagnostics in order to determine whether the model adequately described the data. In addition to the analysis of the proportional hazards assumption, as detailed above, model diagnostics included checking for influential observations[5]. In order to detect any exceptionally influential observations or outliers, dfbeta values, which estimate the changes in the regression coefficients on deletion of each observation in turn, were calculated.

The significance level (p value) was set at 0.05 for all statistical testing. However, weakly significant variables ($p < 0.1$) were also included in the multivariate Cox model.

Results are given as the mean and 95% confidence interval if not otherwise indicated. Binomial confidence intervals were calculated for the survival figures with use of Clinstat (Kingston, Ontario, Canada)[4].

Results

Proportional Hazards Assumption

The proportional hazards assumption was met for age group, gender, diagnosis, time-interval between the primary and revision operations, year of first revision, reason for revision, type of implanted prosthesis, brand of prosthesis, use of bone grafts, primary complications, and fixation method. In other words, the hazards (the risks of repeat revision) associated with these variables did not depend on time. The proportional hazards assumption was not met for the type of hospital (university, central, regional, or other); the hazards associated with different types of hospitals varied over time.

Kaplan-Meier Survival Analysis and Log-Rank Tests

The log-rank tests indicated that the diagnosis, type of implanted prosthesis, primary complications, and type of hospital did not affect the survival of the revision total knee replacements. These variables were excluded from the multivariate Cox analysis. Age group, year of first revision operation, time between the primary and the revision operation, reason for revision, brand of prosthesis, fixation method, use of bone grafts, and to a lesser degree gender ($p = 0.07$) were

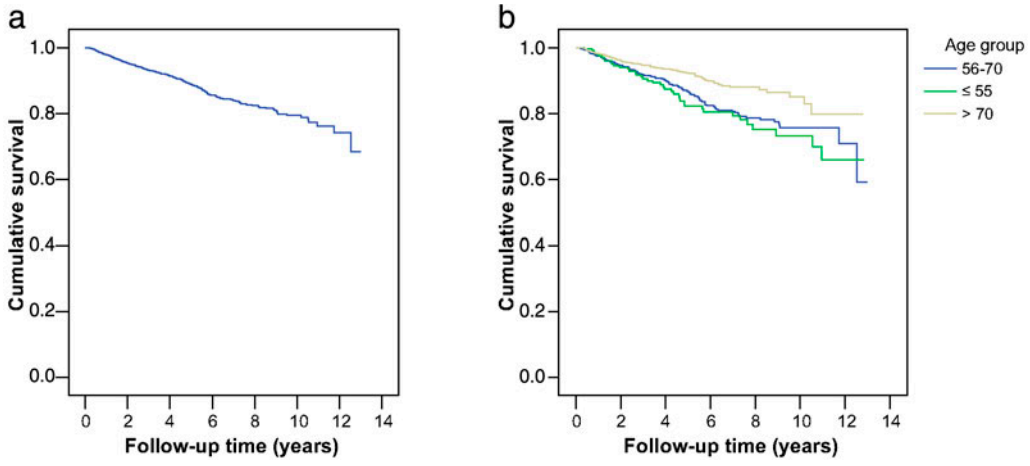

Fig. 1

a: Overall survival of revision prostheses, with repeat revision as the end point. *b:* Survival of revision prostheses in the different age groups. (See text for confidence intervals.)

found to significantly affect the survival of the revision total knee replacements. These variables were included in the multivariate Cox analysis.

Univariate Analyses

Prosthetic survival was estimated with use of the Kaplan-Meier technique, and hazard ratios were estimated with use of univariate Cox analyses (see Appendix). The overall survival of the revision prostheses, with repeat revision as the end point, was 95% (95% confidence interval, 94% to 96%) at two years (1874 knees), 89% (95% confidence interval, 88% to 90%) at five years (944 knees), and 79% (95% confidence interval, 78% to 81%) at ten years (141 knees) (Fig. 1, *a*).

Prosthetic survival at five years, with repeat revision as the end point, was 82% (95% confidence interval, 78% to 87%) for patients younger than fifty-six years of age, 87% (95% confidence interval, 84% to 89%) for those between the ages of fifty-six and seventy years, and 92% (95% confidence interval, 90% to 94%) for those older than the age of seventy years. Prosthetic survival was significantly better for the patients who were older than seventy years than it was for the patients who were younger than seventy years ($p < 0.005$). However, it was not better for the patients between the ages of fifty-six and seventy years than it was for those younger than fifty-six years (Fig. 1, *b*).

Prosthetic survival at five years, with repeat revision as the end point, was 84% (95% confidence interval, 81% to 87%) for men and 90% (95% confidence interval, 88% to 91%) for women ($p = 0.07$). The five-year survival rate was significantly worse ($p < 0.0005$) for patients who had had their first revision operation between 1990 and 1995 (85%; 95% confidence interval, 84% to 87%) than it was for patients who had had their first revision between 1996 and 2002 (92%; 95% confidence interval, 91% to 94%) (Fig. 2). Similarly, the survival rate following the revision arthroplasties performed less than five years after the primary operation (85%; 95% confidence interval, 83% to 87%) was significantly lower ($p < 0.0005$) than the rate following the revisions performed five years or more after the primary operation (92%; 95% confidence interval, 91% to 94%) (Fig. 3).

The survival of revisions done in patients with patellar subluxation was worse ($p < 0.005$) than the overall survival of revisions performed for other reasons (Fig. 4). Pairwise comparisons with use of the log-rank test indicated that the survival of revisions done because of subluxation differed significantly from that of revisions performed because of a fracture of the prosthesis ($p < 0.005$) but did not differ significantly from the survival of revisions due to loosening, malposition, infection, or other patellar complications.

The five-year survival rate, with repeat revision as the end point, was 93% (95% confidence interval, 88% to 95%) for the AGC Dual Articular prosthesis (Biomet, Warsaw, Indiana), 90% (95% confidence interval, 84% to 93%) for the AGC V2 prosthesis (Biomet), 87% (95% confidence interval, 83% to 90%) for the Duracon prosthesis (Stryker Howmedica Osteonics, Allendale, New Jersey), 98% (95% confidence interval, 96% to 99%) for the Duracon Modular prosthesis (Stryker Howmedica Osteonics), 89% (95% confidence interval, 85% to 93%) for the LINK Endo-Modell prosthesis (Waldemar Link, Hamburg, Germany), and 98% (95% confidence interval, 94% to 100%) for the NexGen prosthesis (Zimmer, Warsaw, Indiana). No patient in the registry had had a P.F.C. Sigma prosthesis (DePuy Orthopaedics, Warsaw, Indiana) for five years, but the survival rate of that prosthesis at 4.5 years was 98% (95% confidence interval, 93% to 99%). The NexGen and Duracon Modular pros-

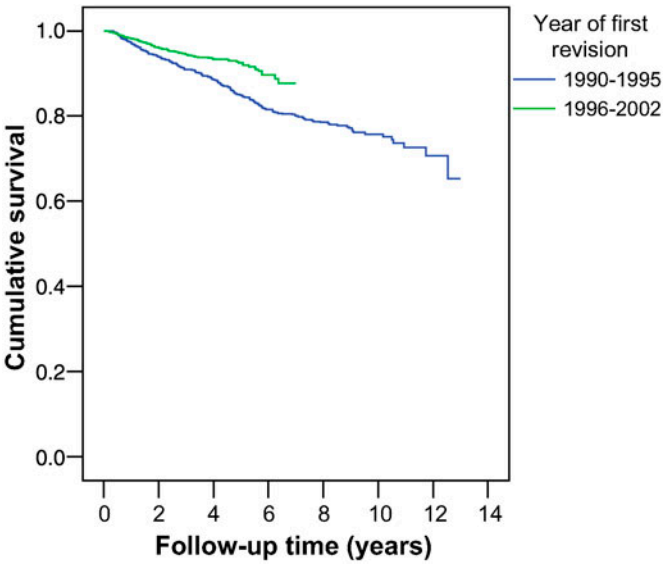

Fig. 2

Survival of revision prostheses according to the year of the first revision, with repeat revision as the end point. (See text for confidence intervals.)

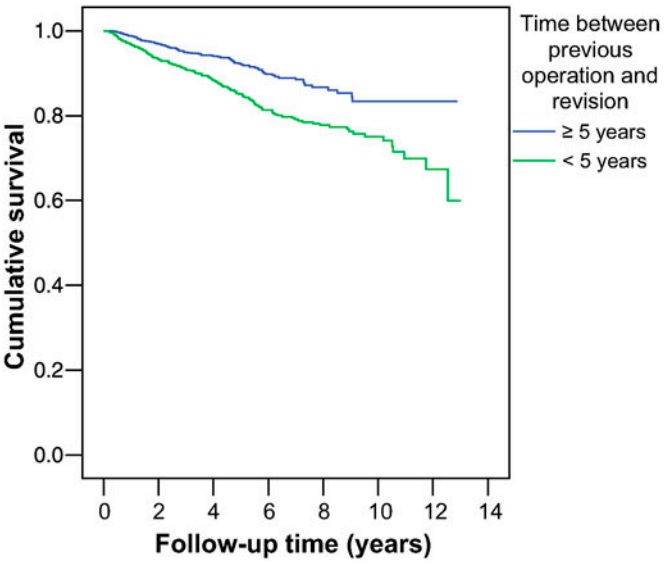

Fig. 3

Survival of revision prostheses according to the time between the previous operation and the revision, with repeat revision as the end point. (See text for confidence intervals.)

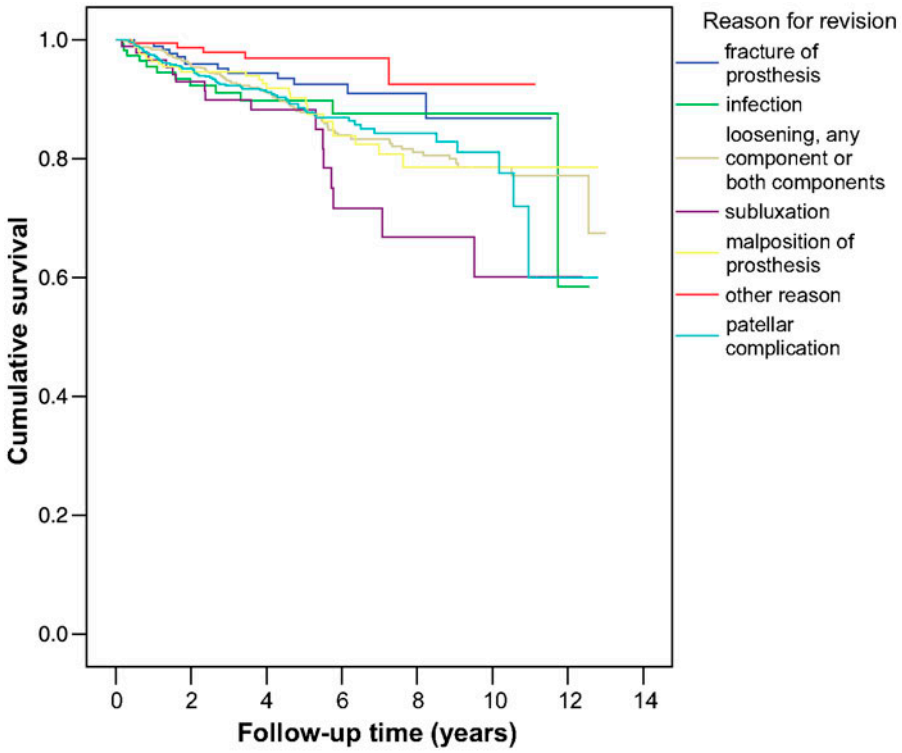

Fig. 4

Survival of revision prostheses according to the reason for revision. The survival following the arthroplasties performed because of patellar subluxation was worse ($p < 0.005$) than the overall survival following the revision arthroplasties performed for other reasons. (See text for confidence intervals.)

theses had better survival rates ($p < 0.05$) than the Duracon implant, which had the shortest time-to-event survival.

Cement fixation ($p < 0.005$) and bone-grafting ($p = 0.05$) improved prosthetic survival, whereas hybrid fixation did not differ significantly from cementless fixation with regard to prosthetic survival (Fig. 5).

The diagnosis, type of prosthesis, primary complications, and type of hospital did not significantly affect the prosthetic survival.

Multivariate Cox Regression Analysis

Significant variables were included in the multivariate Cox analysis. Only age group was significant ($p < 0.005$) in the initial multivariate analysis, which included all of the variables that were found to be significant in the univariate analyses—that is, age group, year of the first revision operation, time between the primary and revision operations, reason for revision, brand of prosthesis, fixation, use of bone grafts, and gender. However, 57% (1514) of the 2637 knees were missing from the analysis, mainly because of missing information regarding the brand of prosthesis and the fixation method. While our statistical software package can include cases with missing values, this was not considered appropriate[6], and a subanalysis was done without those variables (that is, after omission of the brand of prosthesis and fixation method). In this analysis, an age of more than seventy years, having the first operation after 1996, five years or more of service of the primary prosthesis prior to the revision, and absence of patellar subluxation were all found to be significantly associated with improved survival of the revision.

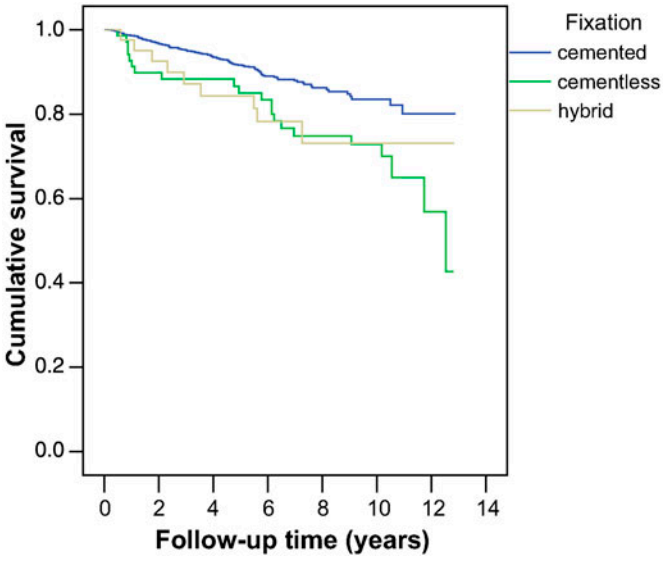

Fig. 5

Survival of revision prostheses according to fixation method. (See text for confidence intervals.)

Model Diagnostics

We found no extreme values or outlier observations that would have dominated the model individually and resulted in a misrepresentative model.

Discussion

One of the assumptions in the Cox regression analysis is that the observations are independent of each other. In reality, the two knees of one patient are not independent of each other, and this must be considered when both knees are operated on. It has, however, been reported that the effect of not accounting for bilateral prostheses is minute, and that the risk of revision of knee prostheses can be analyzed without consideration of the dependency[3]. In the present study, a relatively small proportion (11.3%, 297) of the 2637 knees were in a patient with a bilateral revision, and the survival analyses were carried out without taking bilaterality into account. A subanalysis indicated that bilateral knee revision was associated with better survival than was unilateral knee revision. This finding is in accordance with the finding of better survival of bilateral primary total knee replacements compared with unilateral primary total knee replacements[2].

Age group was a significant predictor of prosthetic survival, with an age of greater than seventy years being associated with better survival ($p < 0.005$). The quality of bone declines with age as a result of senile osteoporosis. However, the reduced physical activity of elderly people diminishes cyclic loading and micromotion. A reduced activity level and low body weight may explain why a long interval between the primary and revision operations predicts a long survival of the revision replacement, but this cannot be proven because physical activity and weight are not recorded in the Finnish Arthroplasty Registry. To some extent, the effect of the patient's age may reflect surgeons' reluctance to perform repeat revisions in elderly and frail patients. Age in itself cannot be considered as a contraindication for revision knee arthroplasty. On the contrary, it seems that revision knee prostheses can be expected to have a long service life in elderly patients.

The outcomes of primary arthroplasties have been relatively good in patients with rheumatoid arthritis[2], although this disease is characterized by destruction of cartilage and bone, ligamentous laxity, and juxta-articular and generalized osteoporosis. The differences in prosthetic survival between knees with a diagnosis of osteoarthritis and those with rheumatoid arthritis, and between men and women, were significant in the study of primary knee replacements ($p < 0.001$ and <0.0001, respectively)[2]. This was not the case in our study of revision knee replacements. This difference may be due to the fact that patients who had already been treated with primary knee arthroplasty had adapted to a reduced activity level so that any pre-existing differences were diminished.

The type of hospital where the patient had undergone the revision arthroplasty (that is, at a university, central, regional, or other type of hospital) was not a significant predictor of prosthetic survival in our analyses. However, it should be noted that, during the follow-up period, specialization in the different fields of orthopaedics very often had not yet developed, even in large units, in Finland[7]. Therefore, some orthopaedic surgeons performed only a few arthroplasties in a year. On the other hand, large hospitals that had achieved a good reputation in a certain field may have attracted more patients with more difficult cases, and this may have worsened the results in those hospitals. Concurrently, the high number of revision operations needed and the long waiting times sometimes led to a revision being performed only when it could no longer be avoided[7]. This may have improved the prosthetic survival figures for individual units. However, the registry provides the nationwide mean for the outcome of revision total knee arthroplasty in Finland, which can be considered to be one of its major advantages.

Patellar subluxation seems to adversely affect the outcome of revision knee replacement, indicating that surgeon-related factors are in part responsible for the failure of some of these procedures. This finding is consistent with those of our previous studies, which demonstrated an excellent or good result in 82% (fifty-eight) of seventy-one patients, a high (94%) eight-year survival rate combined with a low (8.5%) complication rate (six of seventy-one), and very few and asymptomatic radiolucent lines around Total Condylar III revision total knee prostheses (Johnson and Johnson, Braintree, Massachusetts) when these operations were performed by a few experienced revision surgeons[8,9]. Furthermore, only 5% (115) of the 2443 revisions in the present study for which the reason for revision was known resulted from infection. This might to some extent represent underreporting, but that seems unlikely considering the wide coverage of the registry, which was estimated to be 90% to 95% even in the early 1990s, when registration was still voluntary[10].

To improve feedback and quality control, the Finnish Arthroplasty Registry is being further developed so that it will, perhaps in the near future, be possible for individual surgeons to confidentially check online their personal performance in relation to the nationwide norm. The surgeon is responsible for the selection of the brand of prosthesis, the fixation method, and the use of bone grafts, which may affect the survival of revision total knee replacements. Many different brands have been used in Finland, and only the most commonly implanted ones were included in our analyses. Many of the new brands had been used in very small numbers of knees, so more observations are needed before reliable survivorship analyses of those brands in a clinical setting can be performed.

Rand et al. found that primary total knee arthroplasty can be expected to have the most durable results in women who are more than seventy years of age, have inflammatory arthritis, and are treated with certain types of prostheses[2]. They also reported that the cruciate-retaining design was better than the cruciate-sacrificing design in primary total knee arthroplasty. Detailed information about the status of the cruciate ligament was not available in the Finnish Arthroplasty Registry. On the basis of the results of the present study, it can be concluded that revision total knee arthroplasty can be expected to have the most durable results in patients who are

older than seventy years of age and in whom the primary implant had been in service for a long period of time. Absence of patellar subluxation is also a positive indicator.

Gender and diagnosis did not predict the survival of the revised total knee replacements, perhaps because the patients had adapted to a reduced activity level after the primary total knee arthroplasty. Recent advances in implant materials, designs, and operative and fixation techniques presumably have improved implant survival. Indeed, the results of revision total knee surgery in Finland have improved since the early 1990s.

Appendix

eA Tables showing demographic data, factors included in the analyses, and the estimated hazard ratios for the factors are available with the electronic versions of this article, on our web site at jbjs.org (go to the article citation and click on "Supplementary Material") and on our quarterly CD-ROM (call our subscription department, at 781-449-9780, to order the CD-ROM). ■

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Revision total knee arthroplasty with the Total Condylar III system

A comparative analysis of 71 consecutive cases of osteoarthritis or inflammatory arthritis

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Background **As revision total knee arthroplasty surgery is becoming more common, it is necessary to evaluate how individual revision prosthesis systems perform in degenerative and inflammatory arthritides. In this study, results of the use of the Total Condylar III (TC III) system in osteoarthritis (55 knees) were compared to results of its use in inflammatory arthritis (16).**

Methods **Patients were followed radiographically for 5.9 (3.0–10.2) years and clinically for 3.0 (0.2–6.8) years, using re-revision as the endpoint.**

Results **At 1 year after revision and at final follow-up, the total Knee Society knee score, function score and range of motion had improved ($p < 0.001$) with no differences between osteoarthritis and inflammatory arthritis. No knee had definite component loosening, although 23 knees had asymptomatic radiolucent lines. Complications comprised 4 infections, 1 patellar pain syndrome and 1 rupture of the patellar tendon. Using any re-revision of the prosthesis as the endpoint, 5-year survival was 95% and 8-year survival was 94%.**

Interpretation **Concentration of demanding revision knee arthroplasties to a few hands led to good or excellent knee joint knee score results in four-fifths of the patients, and showed good outcome with the TCIII system. In spite of ligamentous laxity, propensity to develop infections, bone destruction and poor general health, patients with inflammatory arthritis had results similar to those with osteoarthritis.**

As the number of knee replacements performed each year continues to increase, and the cumulative number of patients who have a replaced knee concomitantly continues to grow, the number of patients undergoing revision surgery also increases.

The Total Condylar III system (TC III; Johnson and Johnson, Braintree, MA) was designed in 1977 to address the problem of severely deformed knees with ligamentous laxity, which is a challenge for the surgeon in the revision setting (Kim 1987, Donaldson et al. 1988). The use of the TC III prosthesis system in revision total knee arthroplasty has been reported by several authors (Kim 1987, Donaldson et al. 1988, Bush-Joseph et al. 1989, Rand 1991, Rosenberg et al. 1991). Its use in the treatment of complex knees in revision surgery has generally provided satisfactory clinical results.

Elke et al. (1995) reported that after primary total knee arthroplasty, the outcome in patients with rheumatoid arthritis was worse than in patients with osteoarthritis. In contrast, Robertsson et al. (2001) reported no difference in the cumulative revision rate between patients with osteoarthritis and rheumatoid arthritis, based on a large primary total knee replacement material from the Swedish Knee Arthroplasty Register. To our knowledge, no reports comparing the outcome of revision total knee arthroplasty in inflammatory arthritis

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and osteoarthritis have been published before. We therefore compared the outcome in osteoarthritis (n = 55) with that in inflammatory arthritis (n = 16) for revision total knee arthroplasty performed using the TC III system. The hypothesis was that due to better bone stock, patients with osteoarthritis would have better overall results.

Patients and methods

Patients

The individual ID numbers of the Finnish citizens who had undergone revision total knee arthroplasty at Tampere University Hospital until the end of the year 2000 were collected from the patient database of the hospital. Preoperative, operative and follow-up data were collected prospectively and saved in a database specially designed for the follow-up of joint replacement operations (Lehto et al. 1999). In addition, structured follow-up forms of physiotherapists enabled the calculation of the Knee Society score with all its subscales. 71 revision total knee arthroplasties (two bilateral) had been performed in Tampere University Hospital on 69 patients using the TC III system between 1994 and 2000. 16 knees were affected by inflammatory arthritis and 55 by osteoarthritis. Inflammatory arthritis patients had rheumatoid arthritis (n = 12), juvenile chronic arthritis (n = 2), psoriatic arthritis (n = 1) or ankylosing spondylitis (n = 1). There were 56 knees in women and 15 knees in men, and patients had a mean age of 69 (36–85) years. No differences were observed between osteoarthritis and inflammatory arthritis regarding sex (p = 0.8, Chi-square test) or follow-up time (p = 0.6, t-test), but there was a difference in age, with the OA patients being older than the inflammatory arthritis patients (p < 0.001, t-test). The date of the primary total knee arthroplasty and the type of the implanted prosthesis were confirmed from the Finnish Arthroplasty Register maintained by the Finnish National Agency of Medicines (Nevalainen 2003). We also made sure from the National Arthroplasty Register that none of the patients in the current series had had any re-revision arthroplasties in hospitals other than Tampere University Hospital or Coxa Hospital for Joint Replacement. Revision was defined as any new operation during which one or more of the components are exchanged, removed or added (including arthrodesis or amputation).

In inflammatory arthritis, preoperatively, Larsen's grade (Larsen et al. 1977) for radiographic knee destruction was III in 3 cases, IV in 5 cases, V in 6 cases and unknown in 2 cases. The time interval between the primary and revision arthroplasty was 6.8 years on average. In some patients, two or more reasons were recorded for the revision operation and they were as follows: instability (n = 41), polyethylene wear (n = 26), osteolysis (n = 21), aseptic loosening (n = 17), malposition (n = 8), patellar dislocation and/or severe subluxation (n = 8), periprosthetic bone fracture (n = 5), infection (n = 4), knee dislocation (n = 3), or fracture of a prosthetic component (n = 1). All removed prostheses were tri-compartmental, viz. AGC (n = 9), Anametric (n = 1), Duracon (n = 11), Miller-Galante (n = 2), PFC (CR) (n = 2), PFC TC3 (n = 1), PCA (n = 9), PCA Modular (n = 16), Townley Synatomic (n = 15), and Townley (n = 5). All removed prostheses were cruciate-retaining condylar total knee implants except for 1 PFC TCIII, which was infected. Thus, the series comprised 25 cases with PCA or PCA modular and 20 cases with Townley or Townley Synatomic. 2 cases were treated using wedges and 10 cases with structural bone allograft, 8 for bone defects and 2 to restore alignment. 2 of the structural bone allografts were used in inflammatory arthritis patients and 8 in osteoarthritis patients.

Before revision total knee arthroplasty, remarkable angular deformity (> 11° valgus or varus) was present in 9 knees and a milder deformity in 31 knees. The tibiofemoral angle was neutral in 32 knees. Severe anteroposterior instability was observed in 12 knees and severe mediolateral instability was seen in 21 knees. 12 knees were stable in both directions.

2 experienced senior orthopedic surgeons (JP and PH) performed all revision operations except 2 (in which the Larsen's grade had not been recorded). With one exception, in all operations stemmed TC III components were used and fixed with antibiotic-impregnated bone cement (Palacos cum gentamycin). In 1 of the cases revised for infection, tobramycin was also added to this cement. 7 of the eight revisions performed for infections were done in two phases. Patella was re-surfaced in 35 cases. Systematic cefuroxime was used as prophylaxis.

Table 1. Clinical and radiographic results of the TC III-operated patients before the operation compared to the situation after 1 year and at the final follow-up visit. Figures are mean (SD)

	Preoperatively	1 year follow-up	P-value preop. vs 1 year FU	Final follow-up	P-value preop. vs final FU
Knee score	44 (19)	89 (13)	< 0.0001	84 (16)	< 0.0001
Function score	30 (24)	53 (27)	< 0.0001	44 (31)	< 0.0001
Range of motion	78° (42)	102° (21)	< 0.0001)	100° (26)	< 0.0001
Pain score	24 (13)	46 (9)	< 0.0001	42 (13)	< 0.0001
Walking score	19 (8)	29 (8)	< 0.0001	27 (11)	< 0.0001
Stair climbing score	19 (15)	32 (13)	< 0.0001	29 (16)	< 0.0001
Tibiofemoral angle	2° (5)	6° (3)	0.004	6° (3)	< 0.0001
Femoral angle	96° (3)	97° (2)	0.7	96° (2)	0.8
Tibial angle	87° (5)	89° (2)	0.008	89° (2)	0.001
Femoral stem-femur angle	5° (7)	3° (2)	0.02	3° (2)	0.03
Tibial tray, posterior slope	5° (7)	2° (3)	0.005	2° (2)	0.001
Tibial tray, anterior tilt	3° (5)	1° (2)	0.007	1° (2)	< 0.0001
Tibial tray shift (AP) in mm	1.8 (1.9)	1.2 (1.5)	0.1	1.2 (1.6)	0.06
Tibial tray shift (lateral) in mm	1.2 (2.1)	1.1 (1.4)	0.7	0.8 (1.1)	0.2

Clinical and radiographic follow-up

Patients were examined before revision, during the hospitalization and at the outpatient clinic 2 months postoperatively, with further follow-up visits scheduled for 1, 3, 5 and 8 years after operation. All examinations included clinical and radiographic evaluation according to the prevailing routine follow-up regime. For clinical assessment, we used the Knee Society Clinical Rating System (Insall et al. 1989). Knee joint knee scores of 85–100 were considered excellent, 85–70 points good, 69–60 points fair, and less than 60 points poor. Anteroposterior and lateral radiographs of the knee were taken with the patient standing and evaluated using the Knee Society Rating System (Ewald 1989). The bone defects in the femoral and tibial side were classified according to the Anderson Orthopaedic Research Institute (AORI) bone defect classification guidelines (Gerard 1999) with 3 belonging to class T2a, 2 to T2b, 2 to T1, 1 F1T1 and 1 to class F1. Re-revision, arthrodesis, amputation or the death of the patient were used as endpoints. All patients were followed radiographically for 6 (3–10) years. The length of the clinical follow-up was 3 (0.2–6.8) years, as many patients without clinical problems were just evaluated radiographically.

Statistics

We used the Kaplan-Meier analysis for survivorship analysis. For comparison of the pre- and postoperative data and of different groups, we used t-test and Chi-Square test with the level of statistical significance being set at $p < 0.05$. Data were analyzed using SPSS version 11.0.

Results

Clinical results

One year after the revision operation and at the final follow-up visit, improvements were observed in the Knee Society knee score, function score, range of motion, pain score, walking score and stair climbing score compared to the preoperative state before the revision ($p < 0.001$ for all, t-test) (Table 1). 58/71 (0.8) cases had excellent or good outcome (44 excellent and 14 good). 3 cases had fair outcome and 9 cases had a poor outcome (Table 2). No statistically significant differences were observed between inflammatory arthritis and osteoarthritis, although the results obtained in osteoarthritis showed a slight trend toward a better outcome (Tables 2 and 3).

Table 2. Overall clinical results of TC III knee revision surgery in osteoarthritis compared to those in inflammatory arthritis. Based on the knee score values of the Knee Society Clinical Rating System (Insall et al. 1989)

Result	Total	Osteo-arthritis	Inflammatory arthritis
Excellent	44	33	11
Good	14	11	3
Fair	3	1	2
Poor	9	9	0
Total	70 [a]	54	16
Chi-square test		p > 0.05	

[a] Clinical data were missing in one case.

Results of radiography

The tibiofemoral angle (p = 0.04) and posterior slope of the tibial tray 8 (p = 0.05) improved from the preoperative state to the end of the follow-up. In the lateral view, the femoral component was in 5° (SD 7) of flexion preoperatively and in 3° (SD 2) of flexion postoperatively with respect to the femur (p = 0.02, t-test) (Table 1). Except for the posterior slope of the tibial tray and the distance from the center of the tibial component to the center of the tibia in the anteroposterior view, there were no differences between inflammatory arthritis and osteoarthritis (Table 3).

At the tibial or femoral bone-to-cement interfaces, radiolucent lines were seen in 23 of 71 knees (0.3) at the follow-up. 13 knees had radiolucent lines associated with both femoral and tibial components, 9 knees only with the tibial component and 1 knee only with the femoral component. At the femoral bone-to-cement interface, radiolucent lines were mainly seen in zone 1 (four-fifths of all such lines). At the tibial side, the radiolucent lines were seen mainly in zone 1 (two-fifths) and/or 4 (two-fifths of all such lines). The radiolucent lines were thicker than 2 mm (grade III) at the femoral and/or tibial bone-cement interfaces in only 5 cases, and in 3 more cases grade II 1–2 mm radiolucent lines were seen at the tibial bone-cement interface. Otherwise, all radiolucent lines were < 1 mm and represented grade I. Interestingly, none of the patients with inflammatory arthritides had grade II or III radiolucent lines. All 10 patients in whom allograft bone was used had excellent results, with no evidence of resorption, migration or loosening of the components.

Table 3. Comparison of the clinical and radiological outcome after TC III total knee replacement surgery in osteoarthritis and inflammatory arthritis. Values are mean (SD)

	Osteo-arthritis	Inflammatory arthritis	P-value
Gender (men/women), n	12/43	3/13	0.8
Age (year)	72 (7)	59 (13)	<0.001
Follow-up time (year)	5.8 (1.5)	6.1 (2.0)	0.6
Knee scores	82 (17)	88 (12)	0.2
Function score	47 (31)	34 (35)	0.1
Range of motion	100° (24)	98° (32)	0.8
Pain score	41 (14)	44 (11)	0.5
Walking score	27 (11)	22 (12)	0.1
Stair climbing score	29 (16)	24 (19)	0.3
Tibio-femoral angle	6° (3)	6° (3)	0.5
Femoral angle	97° (2)	97° (2)	0.4
Tibial angle	89° (2)	89° (2)	0.5
Femoral stem-femur angle	3° (2)	2° (2)	0.2
Tibial tray, posterior slope	2° (2)	0° (2)	0.009
Tibial tray, anterior tilt	1° (2)	1° (2)	0.6
Tibial tray shift (AP), mm	1.5 (1.9)	0.7 (1.3)	0.04
Tibial tray shift (lateral), mm	0.9 (1.2)	1.3 (1.4)	0.2

Complications

By the end of August 2003, 3 of the 71 implanted prostheses had been removed—all due to infections. In a woman suffering from hypothyroidism and juvenile chronic arthritis treated with methotrexate and prednisolone, the patellar component loosened and caused fistula formation. The patellar component was removed 6 months after the index operation. A year later the whole prosthesis, infected with *Staphylococcus aureus* and *Pseudomonas aeruginosa*, was removed and the joint was debrided. A hinged knee prosthesis was implanted later and has functioned well since then. Another infected prosthesis was removed from another woman after 5 years. Her primary knee replacement was performed for osteoarthritis and she had also had a previous two-stage revision procedure for infected knee replacement. After the removal of the infected prosthesis and long-term antibi-

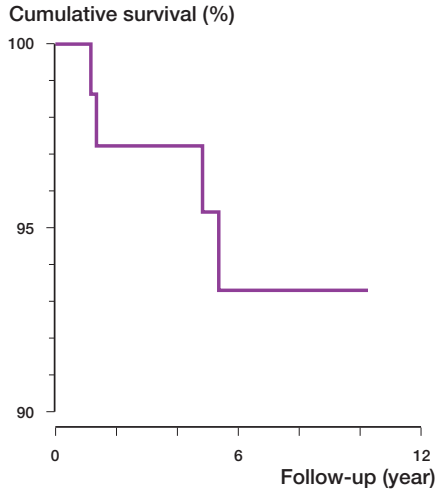

Figure 1. Kaplan Meier Survival curve for TC III knee arthroplasty using any re-revision as the endpoint.

otic treatment, she received a hinged knee prosthesis that has remained infection-free. The infection was caused by coagulase-negative staphylococci. The third failure was also due to infection (with *Staphylococcus aureus*), and occurred 5 years after the revision operation. This male patient suffered from diabetes, peripheral neuropathy and chronic ulceration of the lower limb. It was considered unlikely that the infection could be cured and a thigh amputation was done. His primary total knee replacement had been performed for osteoarthritis and he had also undergone one earlier revision operation.

Other complications which did not, however, require removal of the prosthesis or any of its components were a staphylococcal infection of the prosthesis treated successfully with long-lasting antibiotic therapy, severe patellar pain treated with resurfacing 1 year after the revision arthroplasty, and rupture of the patellar tendon not related to the revision operation.

There were no complications during the early postoperative period at our hospital and none of the patients was referred to our hospital because of such complications. We found no information in the patient records concerning eventual complications treated at another institution.

Survival analysis (Figure 1)

After we had ensured from the Finnish Arthroplasty Register that none of the patients, except for those 3 already mentioned above, had had re-revisions in any other hospital, the situation at August 31, 2003 was used in the survival analysis. Using any re-revision of the prosthesis as the endpoint, 5-year survival was 95% and 8-year survival was 94%. Using removal of the prosthesis as the endpoint of follow-up, the 5-year survival was 97% (CI 92–101) and the 8 year survival was 94% (CI 87–101). The number of patients available for analysis was 43, 20, 9 and 3 at 5, 6, 7 and 8 years, respectively. With any failure as the endpoint, the 5-year survival was 93% (CI 87–100) and the 8-year survival was 91% (CI 82–99). The number of patients available for analysis was 42, 19, 9, and 3 at 5, 6, 7 and 8 years, respectively.

Discussion

Many reports have described the results of complex primary and revision total knee arthroplasties using the TC III system (Insall and Dethmers 1982, Kim 1987, Donaldson et al. 1988, Jacobs et al. 1988, Bush-Joseph et al. 1989, Chotivichit et al. 1991, Hohl et al. 1991, Kavolus et al. 1991, Rand 1991, Rosenberg et al. 1991, Lachiewicz and Falatyn 1996, Peters et al. 1997, Mow and Wiedel 1998). Compared to these studies, ours is the largest when the number of knees is considered. In Rosenberg's paper (1991), 15/36 of the revisions were due to sepsis, whereas in the other papers the main reasons for revision were instability or loosening. The most striking finding is that we reached excellent or good outcomes in 58/71 of the revision total knee arthroplasties with the TC III system, whereas complications occurred in only 4 patients. The consistent use of one total revision knee implant design, together with the concentration of these operations to only a few highly specialized revision surgeons, led to results that were superior to those obtained in a regular setting. In our unit, it was decided very early that these demanding operations should be performed by only 2 surgeons. The 5- and 10-year survival rates were high when any re-revision or removal of the prosthesis was used as endpoint. These high survival rates probably have two main explanations. The learning curve referred to above apparently enabled close to perfect restoration of the alignment, which relieves stresses at

Table 4. Results of TCIII in revision total knee arthroplasty according to the literature

	Number of knees	Main reasons for the revision	Rating system	Excellent or good	Complication rate	Follow-up time (years)
Kim et al. 1987	14	Loosening	HSS	–	2/14	4.2
Donaldson et al. 1988	14	Ligament loss, deformities, instability	HSS	7/14	4/14	2.5–8
Rand et al. 1991	21	Bone loss, instability	HSS	10/21	7/21	4
Rosenberg et al. 1991	36	Sepsis, loosening or instability	HSS	25/36	12/36	3.75
This study	71	Instability	KSS	58/71	6/71	4.2

HSS: the Hospital for Special Surgery knee score; KSS: Knee Society knee score.

the cement-to-bone interface. Recent reports have suggested that radiolucent lines occur in one-third to three-quarters of cases after revision total knee arthroplasty using other prosthetic designs (Insall and Dethmers 1982, Jacobs et al. 1988, Takahashi and Gustilo 1994, Peters et al. 1997, Mow and Wiedel 1998). In our study, only 23 of 71 knees had radiolucent lines, all of them asymptomatic. It is noticeable that all more severe grade II and III radiolucent lines occurred in osteoarthritis, and none in rheumatoid arthritis. This may indicate that patients with rheumatoid arthritis do not, or are not able to, subject their joints to as heavy use as those with osteoarthritis. This may contribute to similar results in these two forms of arthritis in spite of the fact that the initial local joint status and general health status are worse in inflammatory rheumatoid arthritis than in "degenerative" osteoarthritis. We believe that the third-generation cementing technique also contributes to good implant fixation and long-term results compared to those published in previous reports (Kim 1987, Donaldson et al. 1988, Bush-Joseph et al. 1989, Rand 1991, Rosenberg et al. 1991), where there was no indication of the use of modern cementing technique.

Inflammatory arthritis is often associated with cartilage and bone destruction and ligamentous laxity, incompetence and rupture (Ranawat et al. 1984, Stern et al. 1991, 2001, Peters et al. 2001). In addition, the bone stock is impaired by the juxta-articular and generalized osteoporotic changes caused by the disease and its treatment with corticosteroids (Westhovens and Dequeker 2000, Strand and Kavanaugh 2004). The unlinked, semiconstrained TC III system—provided with an enlarged tibial spine in conjunction with a deep femoral well—is specially designed to restore the joint stability and to prevent pathological movement of the prosthetized joint. In this respect, the TC III design apparently puts arthritis patients in line as those suffering from osteoarthritis. Cement fixation of non-modular stems, correct alignment and modest physical demands contribute to a long life in service. These features probably explain why results for inflammatory arthritis were as good as those for osteoarthritis. In general, arthritis patients have increased infection rates due to immunosuppressive medication, extraarticular complications and local joint damage compared to otherwise healthy patients. Only 1 of the 4 patients with an infection in this series had an underlying inflammatory arthritis.

In summary, our results demonstrate that in experienced hands the TC III system performs very well in revision total knee surgery. The unlinked, semi-constrained design allows attainment of excellent or good clinical results together with high medium-term survival rates, if the components are adequately positioned and cemented. Results can apparently be much improved by factors unrelated to the TC III system itself (which has good potential), such as earmarking TC III revision operations to be performed by specialized revision surgeons, together with the use of third-generation cementing techniques.

Contributions of authors

P-YS design of the radiological CRFs, radiographical analysis, statistical analysis, preparation of the manuscript, literature analysis. EJ design of the clinical CRFs, evaluation of the patients files, preparation of the manuscript, statistical analysis. MT development of the idea, seeking permit from the ethical committee and hospital, supervision of the work, organizing of the funding, coordination of activities, literature analysis, preparation of the manuscript. JP and PH all

surgery and clinicians' contribution to the manuscript. YTK development of the idea, supervision of the work, preparation of the manuscript, research management, contacts wit the National Agency of Medicines, literature analysis.

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